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THE ABSORPTION SPECTRUM OF CHLORINE.

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HISTORICAL INTRODUCTION.

IN 1833 Brewster[1] discovered that the spectrum of white light which has passed through a layer of nitrogen peroxide is crossed by a number of black lines. It was natural that physicists should at once begin to look for similar phenomena in the case of other gases, and the colored ones received particular attention. W. H. Miller and Daniell[2] found such absorption lines with iodine, bromine and euchlorine (a mixture of chlorine and its oxides). The lines produced by iodine and bromine appeared to be equidistant and of equal intensity. Using pure chlorine they failed to find anything but a general absorption in the violet. W. A. Miller[3] investigated a number of gases in this connection, and made rough drawings of the absorption spectra of iodine, bromine, nitrogen peroxide, chlorine dioxide, and "perchloride of manganese;" but he also failed to obtain a line absorption due to chlorine. His apparatus, however, consisted only of a

[1] *Phil. Mag.* [3], **2**, 360, 1833; **8**, 384, 1836.

[2] *Pogg. Ann.*, **28**, 386, 1833. [3] *Phil. Mag.* [3], **27**, 81, 1845.

telescope and a single flint-glass prism placed twenty feet from a slit admitting diffused daylight; and it is not certain that he used a column of more than nine inches of chlorine. Later, in 1859, M. E. Robiquet[1] stated that there was not the least appearance of lines in the spectrum of chlorine even when the light had passed through 4.5 meters of the gas, but that the spectrum consisted of a general illumination in the green and yellow. His source of light was an incandescent platinum wire, and he used a single-prism spectroscope. Many other attempts were made to discover a chlorine line absorption spectrum, as the known similarities between this gas and bromine and iodine led to the belief that such a spectrum existed; but all these attempts failed on account of the lack of suitable apparatus. Finally, in 1869, Morren,[2] using a spectroscope of fine flint-glass prisms and a length of two meters of chlorine, succeeded in obtaining the desired spectrum. He gives a general description of its appearance. According to his observations the lines begin above the *b* solar lines and extend below F to about $\lambda 4820$. Beyond $\lambda 4750$ the sunlight is totally absorbed. The lines differ in intensity, width and grouping, and are placed irregularly. He mentions having made a drawing, but it was apparently not published. Later, Gernez[3] unaware of the previous work of Morren, rediscovered the lines. He tried first a length of 1.5 meters of chlorine at atmospheric pressure, but he obtained the lines more distinctly by using a tube of chlorine three times as long. His spectroscope had two prisms, and a Drummond lamp was the source of light. He states that this gives a spectrum extending into the "violet," that the lines begin a little below the D lines and extend to the "violet," which is totally absorbed. He remarks also that the lines are unlike those of bromine and iodine in having variable intensity and irregular grouping.

Liveing and Dewar[4] have investigated the general absorption of chlorine in the ultra-violet. As a source of light they used

[1] *C. R.*, **49**, 606, 1859.

[2] *Pogg. Ann.*, **137**, 165, 1869; *C. R.* **68**, 376, 1869.

[3] *C. R.*, **74**, 660, 1872.

[4] *Chem. News*, **47**, 121, 1883.

the spark of an induction coil between iron electrodes. The tubes used had quartz ends and the dispersing prism was of quartz. They found that a small quantity of chlorine gave one absorption band stretching from λ3560–λ3020. As the quantity of chlorine was increased the band widened, and the following different measurements of its width are given — λ3968–λ2755; λ4415–λ2665; λ4650–λ2630; with the greatest amount of chlorine used they found that the absorption stopped at λ2550.

The absorptive power of chlorine for the long heat rays was investigated by Tyndall.[1] He found that, excepting air, oxygen, nitrogen and hydrogen, it absorbed less than any other gas on which he experimented. K. Ångström and W. Palmaer[2] found that the infra-red spectrum consisted of a single band, which with an Argand lamp as source of radiation, and a column of 11.8cm of chlorine, extended from λ32300 to λ60700 (Å. U.), the maximum absorption being at λ42800.

Liquid chlorine is said by Gänge[3] to absorb the extreme red down to about λ6970 or λ6860; from there on the light is transmitted to about λ5120, from which point absorption begins again, and is complete at λ5030.

The emission spectrum of chlorine has been investigated at different times. Plücker[4] was the first to obtain it, but in his first experiments the spectrum did not last long enough for purposes of drawing; later, together with Hittorf,[5] he studied its spectrum as obtained from Geissler tubes and made a careful drawing of it. Van der Willigen[6] and Salet[7] studied the spectrum of the gas at atmospheric pressure. The former used the spark from an induction coil, the latter used a Holtz machine;

[1] TYNDALL, *Contributions to Molecular Physics in the Domain of Radiant Heat*, p. 80.

[2] *Öfversigt af K. Vet. Akad. Förhandl.*, No. 6, 389, 1893.

[3] GÄNGE, *Lehrbuch der angewandten Optik in der Chemie*, p. 217.

[4] *Pogg. Ann.*, **106**, 83, 1858.

[5] *Phil. Trans.*, **155**, 24, 1865.

[6] *Pogg. Ann.*, **106**, 624, 1859.

[7] *Ann. de Chim. et de Phys.* [4], **28**, 24, 1873.

both give drawings of the spectrum obtained. Ångström[1] and Hasselberg[2] measured a few lines. The latter remarked them in using vacuum tubes the glass walls of which contained chlorine. Lecoq de Boisbaudran[3] and Eugen Demarçay[4] identified as belonging to chlorine some lines obtained from the spark discharge between a platinum wire and hydrochloric acid; both give measurements on these lines. Ciamician[5] studied the relation of the spectrum of chlorine to the spectra of iodine and bromine; also the variation in the aspect of the chlorine lines for different pressures. The latest and most accurate measurements are by Eder and Valenta,[6] who used a Rowland grating and photographed almost the entire spectrum, finding about four hundred lines. The majority of these lines are in the ultra-violet or violet, but they extend through the blue and green into the yellow; and some, which Eder and Valenta observed but did not measure, are in the red. Those in the violet and ultra-violet are characterized as sharper than those in the green or yellow, the latter being, for the most part, broad or indistinct.

Investigations on the absorption spectrum of chlorine other than those already mentioned, do not appear to have been made, and in no case are measurements of the wave-lengths given. In a recent paper J. Koenigsberger,[7] referring to the effect of temperature on the line absorption of gases, speaks as if Brewster had investigated the absorption spectrum of chlorine, but he gives no exact reference. I have made careful search, but have been unable to find any work of Brewster's on the subject.

The study of the line absorption spectra of gases has

[1] *C. R.*, **73**, 369. [2] *Bull. de l'Acad. de St. Petersb.*, **28**, 405, 1881.

[3] LECOQ DE BOISBAUDRAN, *Spectres lumineux*, 1874.

[4] EUGEN DEMARÇAY, *Spectres lumineux*, 1895.

[5] *Sitzungsb. d. kais. Akad. d. Wiss.*, Wien, **77**, 839, 1878; **78**, 4 Abth., 1878.

[6] *Denksehr. d. kais. Akad. d. Wiss.*, Wien, **68**, 1899.

[7] *Ann. der Phys.* [4], **4**, 806, 1901.

received, on the whole, very little attention since the use of gratings has made possible more exact measurements. Considerable work has been done on the band absorption of liquids including the effect of temperature, etc. The influence of single solvents and of mixtures of solvents has also been investigated. There are some measurements on the absorption of vapors, but the apparatus used has been of low dispersive power, and the measurements are accordingly not very exact. The absorption of the various constituents of the air has been investigated and compared with the telluric lines of the solar spectrum, but few independent measurements of the wave-lengths have been made. From the reversal of emission lines, the absorption of hot vapors has been deduced. The work of Hasselberg[1] on the absorption of iodine and bromine is still the main example of an attempt to measure the lines in absorption spectra of gases under normal conditions as exactly as is done for emission spectra. This is is the more to be regretted as it is certain that a study of the line absorption spectra of gases in connection with emission spectra at low temperatures must increase our knowledge of the processes involved in both the emission and absorption of light, and aid us ultimately in picturing the constitution of the molecules. A further investigation of the absorption spectrum of chlorine seemed, therefore, not without interest, and the following pages give the details of some experiments on this subject.

APPARATUS.

The physical laboratory at Bryn Mawr College is provided with a 15 ft. Rowland grating of 15,000 lines to the inch and a ruled surface of 11×4 cm, which is mounted after the usual Rowland method. The camera holds plates 30.5×3.5 cm, and is provided with the arrangement used by Rowland[2] for comparison spectra.

Plates made by C. S. Schleussner, of Frankfurt a. M., were

[1] *Mem. de l'acad. de St. Petersb.*, 7, 36, No. 17, 1889; *K. Svenska Vet. akad. Handl.* No. 3, 24, 1891.

[2] *Phil. Mag.* [5], 27, 378.

used to photograph in the blue and violet, and Seed's orthochromatic plates or Cramer's isochromatic plates were used in the green and yellow. The developer used throughout the investigation was mixed after the formula given by L. E. Jewell.[1]

In the green and yellow of the first order for slit width about 0.001 in. the time of exposure for the source alone, whether Sun or electric arc, was from six to ten minutes; with the tube of chlorine interposed it was from twenty to thirty minutes. In the second order and with slit width about 0.002 in. the exposures were about three times those given above.

On account of the large number of standard lines which it provides, the Sun is the most desirable source of light for this kind of work; but as the solar beam after entering the grating room from the heliostat traverses a distance of only 34 cm before falling on the slit, it was questionable whether this would admit a sufficiently long column of chlorine to produce the desired spectrum. The attempts of earlier investigators with columns of this length failed to show any traces of absorption lines; but as the apparatus at their disposal was so different from that here used it was thought worth while to make a trial. The result showed that this length of column was insufficient; there were suggestions of lines, but the absorption was too weak to make certain of the existence of lines without further confirmation.

A tube 65 cm long was then used with the arc as the source of light. Decided absorption lines appeared; but as increasing the column of chlorine promised to intensify the lines, a tube 1.37 meters long, the longest which could be placed between the condensing lens and the slit, was finally used. This tube was of glass of 5.2 cm internal diameter and was closed with plane glass plates. Metal caps screwed on to metal collars, which were cemented on to the outside of the tube, held the glass plates in

[1] ASTROPHYSICAL JOURNAL, 11, 242, 1900.

place. Holes bored in the glass tube corresponding to similar ones in the collars, to which nipples were fitted, served as inlet and outlet for the chlorine; later, it was found better to allow the metal collars to project beyond the tube in order to avoid boring the glass, as the cementing on of the collars seemed to strain the glass to such an extent that boring a hole in it almost invariably caused cracking.

An attempt was made to use this tube with the Sun as source of light by placing it between the slit and the grating; with large slit with 0.0007 in., a fairly good photograph was obtainable, but diminishing the slit-width increased the indistinctness of the lines until they became broad and fuzzy. This, doubtless, was due to the larger proportion of light reflected from the sides of the tube. Blackening the tube with lampblack did not overcome the difficulty sufficiently to make this method feasible.

Another tube for use with solar light was made of steel, 33.2 cm long and 1.6 cm internal diameter. It also was provided with caps which screwed over the ends and held on the glass plates. It was hoped that this would hold the gas under more than atmospheric pressure, and that the effect of a longer tube would be thus obtained. However, the first form of end and valve leaked under pressure, as no form of packing could be found which chlorine would not attack. The steel itself was attacked, as was expected, but the ferric chloride soon formed a layer over the surface and protected the rest in great measure; and since it is a solid its presence cannot invalidate the results. When, however, particles of the chloride fell on the glass ends they became very troublesome and necessitated the removal of the caps in order to clean the glass. This proceeding was attended with difficulties as a leak of chlorine through the cap stuck tube and cap together. After some ineffectual attempts to obviate these difficulties the scheme was abandoned for the time being.

It was then determined to utilize the space between the total

reflecting prism and the condensing lens for the solar beam, which latter lens is in a metal tube projecting outside from the wall of the room. A glass tube 80 cm long and 5.3 cm internal diameter was made for use in this position. Distinct absorption lines were thus obtained; those towards the less refrangible end were still faint. Photographs were taken of all parts of the visible chlorine absorption spectrum from the D lines down, using both arc and Sun as the source of light.

To obtain the ultra-violet portion the glass ends were removed from the last-mentioned tube and were replaced by lead ones in which were inserted oblong quartz plates put in with soluble glass or soft wax. These were 2.5×4.0 cm, the largest possessed by the laboratory. For the extreme portion the Sun could not be used as a source of light, as the heliostat mirror at present in use is not of speculum metal, but of silvered glass, and the more refrangible rays are already absorbed. The arc was therefore used with a system of two quartz lenses.

The chlorine for these experiments was at first prepared from sulphuric acid, sodium chloride, and manganese dioxide in the usual way; that used later was taken from a cylinder of liquid chlorine, supplied by Messrs. Eimer and Amend, of New York, passed through washing and drying bottles and then led into the tubes. This cylinder gave a most convenient supply at any desired time, and the spectrum obtained with the chlorine from this source corresponded exactly with that obtained from the gas prepared by myself.

Further tests were made, however, for impurities which might cause errors in the results. As such, chlorine oxides were especially to be feared; but very careful tests showed that no trace of chlorine oxides was present. Carbon dioxide and a small fraction of air were found, the two making up in an extreme case one fourth of the total volume. Carbon dioxide has, however, no absorption in the visible part of the spectrum. P. Ballei[1] states that 75 meters of this gas under pressures up to

[1] *Nuovo Cimento*, 9, 172, 1899.

twenty atmospheres showed no trace of an absorption spectrum; thus its presence, mixed in with the chlorine, but forming no chemical compound with it, can have no effect except to change the total pressure. The same is true for the small amount of air present.

For assistance in making the analysis of the chlorine, my thanks are due to Dr. Kohler, professor of chemistry at Bryn Mawr College.

MEASUREMENTS.

The pitch of the screw of the dividing engine with which the plates were measured is approximately 1 mm; the head reads to 0.005 mm and the vernier to 0.001 mm. The errors of turn and of run of the screw were investigated before final measurements were made.

To determine a possible error in turn the distance along a given line between two fine lines drawn with a diamond point on steel, less than a tenth of a millimeter apart, was measured, starting from different positions of the head. For this purpose a microscope of magnifying power 35 was used. The variation in the readings was found to be not greater than the possible error of setting. The greatest deviation from the mean was 0.0015 mm and the average deviation was less than one half of this amount, or not more than 0.002 Å. U., when turned into wave-lengths. As the lines to be measured were not sufficiently sharply defined to attain to greater accuracy than this, no correction was applied.

The error in turn was examined over 15 cm of the screw, and found similarly to be negligible.

The microscope used for measuring the lines on the photographic plates had a magnifying power of 16. The wave-lengths were computed in the usual way from those of standard lines. The wave-lengths of all reference lines used were taken from Rowland's table of standard wave-lengths. On the arc plates there was some difficulty in obtaining standards, but sufficient were always found from which to calculate the reduction

factor; other Rowland lines were sometimes used for comparison.

Both Sun and arc plates had their disadvantages. Even with the comparison solar spectrum photographed beside the solar plus the chlorine absorption spectrum, it is difficult to decide at times whether a line belongs to chlorine or not. If a line is so close to a solar line as to be inseparable from it, though its existence may be apparent from the broadening of the solar line, or from the increase of intensity, accurate setting is very difficult without some *a priori* knowledge of the width and character of the line. On the other hand, when the light from the glowing positive pole of the electric arc gives the spectrum the plates abound with black lines on a continuous dark background. The chlorine absorption lines appear, then, as white lines mixed in with black ones, and the danger arises of mistaking for an absorption line, the narrow space between two adjacent black lines, which is white merely by contrast. As a great number of photographs have been examined in this respect it is scarcely possible that any lines measured have been thus mistaken. There is the possibility that a chlorine line may fall on a black line, in which case it may not appear as an absorption line at all. Especially is this possible in a part of the green carbon band.

All of the lines given have been measured on arc plates, a large number have been measured also on Sun plates, as will be seen from the tables. As many of the lines are ill-defined, the second order plates did not offer much advantage over those of the first order, except for those lines which are broken up into doubles in the second order, and as the time of exposure in the second order was very much longer, the first order was used more extensively. In the first order 1 mm on a plate corresponds to 3.6 Å U., approximately.

The average mean error of measurement is about 0.015 Å. U. As stated above, the only exact measurements of this kind previously made are due to Hasselberg. He claims an accuracy

of 0.02 or 0.03 Å. U. for his measurements on the sharpest lines of the absorption spectrum of iodine, lines which he used as normals; and as it is to be inferred that the lines of the bromine spectrum are less well-defined than those of iodine, the general accuracy is probably not so great for the measurements on the bromine spectrum. The error, then, in the present measurements is almost certainly less than that in previous work on absorption spectra, and is also not greater than that of the general measurements on emission spectra.

Explanation of Table I.—The measurements are given in the following table. The first column contains the number of separate measurements on the line; an *s* after the number indicates that some of the measurements were made on Sun plates. The second column contains the wave-length in Ångström units; the third, the mean error; and the fourth the intensities, reckoned on the scale 0, 1, 2, . . . 10, and details as to the appearance of the lines. Intensity 1 is given to the faintest lines that are clearly visible; 0 to lines that are not so; and 10 to the strongest lines.

N signifies ill-defined; *s*, sharp; *b*, broad; *vb*, very broad; *d*, double; *d?*, possibly double. From λ 4799 to λ 5165 the numbers are given for chlorine at one atmosphere pressure. From λ 5165 to λ 5218 measurements and intensities are given for a meter of chlorine both at atmospheric pressure, and at a pressure of two and a half atmospheres; from λ 5218 on the measurements are for a pressure of two and a half atmospheres.

TABLE I.

n	Wave-length	Mean error	Intensity and character
3	4799.11	0.017	0 *N*
4	4799.951	.011	0
3	4800.95	.015	0
4	4802.066	.011	0
3	4802.759	.011	0
6	4803.322	.013	1
3	4804.560	.023	0
2	4805.13	.037	0
4	4805.94	.029	0
5	4806.57	.014	2
5	4807.081	.011	2
2	4807.38	.003	0
5	4809.081	.012	2
3	4809.66	.012	1
4	4809.949	.021	1
4	4810.603	.014	3
8 *s*	4811.168	.006	4
5 *s*	4811.899	.013	3
4	4812.598	.010	2 *N*
5 *s*	4813.047	.013	2 *N*
4	4813.747	.003	3 *N b*
6 *s*	4814.393	.008	3 *N b*
4	4814.77	.030	0
8 *s*	4815.353	.008	2 *b*
7 *s*	4815.832	.014	2 *b*
3	4816.43	.019	0
3	4816.77	.003	0
2	4817.44	.016	1 *N*
4	4817.927	.009	4
3	4818.34	.026	1
4 *s*	4818.75	.021	2
6 *s*	4819.15	.028	1 *b N*
4 *s*	4820.059	.011	2 *N*
3	4820.45	.022	2 *N*
4	4821.08	.014	3 *N*
7 *s*	4821.955	.012	2 *b*
6 *s*	4822.652	.009	2 *b N d?*
2	4823.22	.022	2 *N*
3	4823.69	.018	2 *N*
3	4824.21	.010	2 *b N*
8 *s*	4824.735	.007	2
5 *s*	4825.888	.013	4 *vb*
8 *s*	4826.887	.011	4 *b*
5 *s*	4827.630	.008	4 *b d?*
6 *s*	4828.614	.012	4 *b*
4	4829.41	.018	3
6 *s*	4830.068	.011	3 *b*
8 *s*	4830.418	.005	3 *b*
3	4831.315	.003	3 *vb d*
5 *s*	4832.057	.009	2
4 *s*	4832.67	.020	3 *N*
3	4833.13	.036	1
6 *s*	4833.83	0.015	2 *N d*
6 *s*	4834.263	.010	2
4 *s*	4834.729	.012	2
8 *s*	4835.205	.007	4
5 *s*	4835.79	.018	3 *N*
5 *s*	4836.495	.014	4 *N*
9 *s*	4837.073	.006	4 *d?*
4 *s*	4837.54	.016	1
7 *s*	4838.02	.016	7 *b*
4	4838.94	.012	3
6 *s*	4839.435	.013	2
4	4839.85	.018	2 *N*
3	4840.31	.006	1 *N*
5 *s*	4840.973	.012	10
3 *s*	4841.41	.012	1
3 *s*	4841.667	.004	2
2	4841.96	.043	2 *N*
3	4842.93	.026	3 *b*
2	4843.21	.011	2
3	4843.71	.010	2
2	4844.10	.020	2 *N*
5 *s*	4844.601	.012	2 *N*
7 *s*	4845.209	.008	5 *b*
5 *s*	4846.017	.009	3
8 *s*	4846.534	.005	6
3 *s*	4847.13	.004	0
7 *s*	4847.736	.010	3 *N*
3	4848.49	.022	2
5 *s*	4849.122	.006	3 *b*
4 *s*	4849.647	.006	1
9 *s*	4850.141	.007	3 *N*
9 *s*	4850.605	.009	3 *N*
9 *s*	4851.062	.007	3 *N*
4	4851.637	.007	1 *N*
7 *s*	4852.158	.009	5
6 *s*	4852.532	.008	2
7 *s*	4853.30	.011	3 *d*
4	4853.99	.015	1 *N*
9 *s*	4854.411	.008	4
4	4855.070	.011	1 *N*
5	4855.595	.012	8 *s*
4	4855.96	.010	1
4 *s*	4956.647	.001	2
6 *s*	4856.966	.016	2
3 *s*	4857.30	.023	1 *N*
6 *s*	4857.867	.010	9 *s*
4 *s*	4858.39	.016	1
4 *s*	4858.763	.008	1
4	4859.173	.010	5 *b*
6 *s*	4859.761	.012	5 *b*
3	4860.37	.013	2 *d?*
3 *s*	4860.84	.021	2 *N*

TABLE I—*Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
4	4861.472	0.005	6	4	4888.63	0.016	2 *N*
4	4861.985	.014	2 *N*	5	4888.966	.012	4 *b*
3	4862.34	.019	2 *N*	4 *s*	4889.851	.007	1
8 *s*	4863.126	.008	5 *b*	5 *s*	4890.23	.019	2 *N*
4	4863.36	.011	1	5 *s*	4890.503	.009	2 *N*
5	4864.127	.004	5 *b d ?*	3 *s*	4891.05	.031	0
6	4864.991	.011	5 *b d*	3	4891.42	.014	2 *N*
3	4865.78	.023	0	4	4891.829	.013	3 *s*
4 *s*	4866.118	.016	2	2	4892.20	.002	0
4	4866.625	.007	6	2	4892.40	.018	0
5 *s*	4867.331	.006	3 *b*	4 *s*	4892.801	.006	2
4	4867.796	.010	1 *b N*	3	4893.11	.033	1 *N*
6	4868.499	.007	10	3	4893.52	.026	2 *N*
4	4868.90	.011	1	8 *s*	4893.695	.010	3 *N*
4 *s*	4869.83	.022	4 *b N*	4 *s*	4894.20	.021	1 *N*
4	4870.398	.009	4 *b*	4 *s*	4894.49	.022	1 *N d*
5	4871.123	.006	7 *b*	3	4894.77	.043	0
3	4872.19	.037	2 *N*	8 *s*	4895.317	.008	4 *b*
4	4872.526	.008	3 *N*	3	4895.69	.017	0
4	4873.11	.018	2 *N*	9 *s*	4895.950	.011	4 *b N*
5	4873.60	.018	2 *N*	4	4896.35	.021	2 *N*
3	4874.088	.006	3 *b N*	4	4896.888	.007	2
4 *s*	4874.650	.010	4	4 *s*	4897.119	.009	3
3 *s*	4875.19	.024	2 *b*	8 *s*	4897.572	.011	4 *b*
4	4875.801	.016	4	3	4897.75	.017	3 *N*
4	4876.180	.003	3	5 *s*	4898.285	.014	2
4	4876.509	.008	3	3 *s*	4899.218	.008	2 *b N*
4	4876.871	.002	3	3 *s*	4899.45	.020	2 *N*
7 *s*	4877.331	.010	4 *b*	7	4899.991	.011	4
2	4877.92	.009	4 *b N*	4	4900.41	.018	2 *N*
4	4878.15	.023	4 *vb*	6 *s*	4901.074	.006	3 *N*
4 *s*	4878.869	.012	4	4 *s*	4901.366	.010	2
4 *s*	4879.124	.012	4	4 *s*	4901.61	.016	2 *b N*
5 *s*	4879.777	.012	1	11 *s*	4902.465	.007	6 *s*
3 *s*	4880.11	.042	1	7	4903.10	.019	2 *N*
5 *s*	4880.452	.014	2	5	4903.57	.022	4 *N*
5 *s*	4881.060	.012	4 *b*	8 *s*	4904.304	.005	4 *s*
3 *s*	4881.45	.021	3	5	4904.767	.011	1 *N*
3	4882.00	.012	2	7	4905.275	.013	4
2	4882.23	.004	2	9 *s*	4905.702	.009	4
3 *s*	4882.84	.029	3 *N*	5 *s*	4906.40	.024	0
3 *s*	4883.12	.027	3 *N*	7	4906.782	.013	0
3 *s*	4883.47	.007	1	7 *s*	4907.383	.011	6
4	4883.94	.016	2 *N*	6	4907.830	.012	1
3 *s*	4884.46	.042	1	5	4908.315	.009	3 *s*
4 *s*	4884.874	.005	4 *b*	5 *s*	4908.913	.009	2 *b d ?*
4 *s*	4885.112	.018	4	3	4909.796	.004	4
4	4885.737	.008	1	3	4910.155	.001	4
4	4886.03	.018	1	2	4910.49	.057	0
4	4887.08	.014	2 *b d*	4	4911.14	.015	1
4	4887.543	.008	3 *s*	5 *s*	4911.715	.013	4
4	4888.05	.027	1	4	4912.15	.022	4

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
5 *s*	4912.744	0.008	1	4 *s*	4942.375	0.009	4
4 *s*	4913.060	.007	1	5 *s*	4942.905	.016	4
7 *s*	4913.433	.009	4	7 *s*	4943.703	.009	3 *N*
4	4914.089	.011	1	6 *s*	4944.338	.009	3 *b d ?*
4	4914.50	.019	1	18 *s*	4945.031	.004	6 *s*
6 *s*	4915.058	.012	3	4	4945.531	.018	4
5 *s*	4915.394	.015	2	3	4946.39	.027	4 *b*
6 *s*	4915.977	.009	2 *N*	7 *s*	4947.287	.006	4
6 *s*	4916.408	.010	2	7 *s*	4947.804	.007	5
7 *s*	4916.868	.013	2 *N*	4 *s*	4948.439	.003	1
4	4917.33	.017	2 *N*	3 *s*	4949.01	.026	1
6 *s*	4917.943	.011	7	2	4949.48	.002	1 *N*
4	4918.52	.018	1 *N*	3 *s*	4949.97	.018	2 *N*
3	4919.07	.007	1 *N*	2	4950.44	.006	1 *N*
3	4919.92	.024	3	4 *s*	4951.06	.016	4 *N* triplet?
3	4920.33	.006	2	4 *s*	4951.67	.026	2 *N*
3	4920.88	.029	2 *N*	2	4952.21	.002	2 *N*
5	4921.448	.006	4	2	4952.65	.018	2 *N*
4	4921.984	.015	4	4	4953.32	.017	6 *b*
2	4922.52	.011	2	3	4953.77	.018	0
4 *s*	4923.012	.010	2	6 *s*	4954.31	.018	4 broadened on red side
5 *s*	4923.530	.011	4				
2	4924.28	.010	4	4	4954.93	.017	4
3	4924.86	.019	3	2	4955.54	.005	1
2	4925.74	.030	2 *N*	4 *s*	4956.02	.018	3 *N*
3 *s*	4926.49	.004	2 *bN*	5 *s*	4956.477	.013	2
8 *s*	4927.213	.008	3	2	4956.79	.011	1
2 *s*	4927.69	.009	0	3	4957.10	.017	2
6	4928.149	.009	5	2	4957.62	.018	2
7 *s*	4928.796	.008	4 *b*	5 *s*	4958.204	.007	3
9 *s*	4929.547	.009	5 *b*	18 *s*	4958.736	.004	4 *s*
5	4930.397	.018	5 *b*	4 *s*	4959.366	.011	3
6 *s*	4931.144	.007	5 •	4 *s*	4960.13	.023	3 *b N*
2	4931.47	.015	0	5 *s*	4960.767	.008	4
2	4932.11	.016	1	3 *s*	4961.33	.013	1 *N*
6 *s*	4932.85	.019	4	3	4961.987	.003	2 *b*
3	4933.86	.013	1 *b d N*	2	4962.74	.019	3
5 *s*	4934.77	.012	2 *b N*	5 *s*	4963.277	.009	3
4 *s*	4935.123	.014	2 *N*	4 *s*	4964.233	.009	4 *b d*
4 *s*	4935.583	.010	2 *N*	3 *s*	4964.872	.014	2
4	4935.85	.017	3	4 *s*	4965.535	.012	4 *b d*
5 *s*	4936.339	.009	2	2	4966.11	.030	0
6 *s*	4936.695	.015	5	3 *s*	4966.597	.012	4
4	4937.20	.010	2	5 *s*	4966.977	.011	4
4 *s*	4937.727	.017	2	2	4967.81	.020	1
3	4938.61	.018	2 *N* haze	2	4968.24	.044	4 *N*
3	4939.03	.016	2 haze	3	4968.99	.009	2
3	4939.60	.011	2 *N*	7 *s*	4969.533	.009	6 *b*
4	4940.11	.020	2 *N*	2	4970.06	.023	2
7 *s*	4940.655	.007	4	3 *s*	4970.522	.013	6 *b*
4 *s*	4941.290	.010	2	2	4970.89	.037	2 *N*
6 *s*	4941.830	.013	4 *b*	2	4971.69	.002	2

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
5 *s*	4972.252	0.007	4	2	5004.11	0.021	2
2	4972.77	.004	2	2	5004.95	.012	2 *N*
4 *s*	4973.264	.011	5	4 *s*	5005.34	.024	4 *N*
4	4974.294	.009	4 *N*	2	5006.25	.007	2
5	4974.912	.007	4 *s*	4 *s*	5006.92	.025	2 *N*
3	4975.48	.029	2 *b N*	4 *s*	5007.685	.010	3 *b N*
2	4976.54	.007	1 *N*	5 *s*	5008.594	.015	5 *v b*
5 *s*	4976.943	.014	2 *N*	2	5009.32	.018	1 *b N*
2	4977.43	.092	0 *N*	2	5009.81	.021	2 *N*
2	4978.211	.003	6	2	5010.154	.004	4
2	4978.76	.042	2 *b N*	2	5010.64	.100	0 *N*
2	4979.76	.019	3 *N d?*	2	5011.20	.011	1
2	4980.42	.017	7	4 *s*	5011.637	.010	1
5 *s*	4981.114	.009	4	4	5012.104	.005	8 *s*
3	4981.67	.021	8	2	5012.78	.024	2 *N*
4 *s*	4982.337	.004	4	3	5013.59	.005	1 *b N*
2	4982.70	.001	2	2	5014.06	.025	1
3	4983.14	.015	2	3	5014.47	.016	4 *b*
2	4984.31	.019	5 *N*	2	5014.70	.050	0
2	4984.75	.017	0	3	5015.13	.021	2
2	4985.16	.009	3	5 *s*	5015.740	.007	4
3	4985.71	.008	3	2	5016.55	.031	5 *N*
3	4986.23	.020	5	2	5016.96	.030	3
5 *s*	4987.18	.015	2 *b*	2	5017.42	.029	0
5 *s*	4987.854	.008	3	3	5017.69	.024	5
3 *s*	4988.165	.012	2	2	5018.60	.019	3
5 *s*	4988.576	.011	6 *s*	2	5018.95	.013	3
2	4989.06	.022	1	5 *s*	5019.425	.009	6
2	4989.55	.003	3	2	5020.49	.038	4 *vb d?*
3 *s*	4989.906	.010	3	5 *s*	5021.313	.016	4
4 *s*	4990.408	.011	4	2	5021.67	.015	1
4	4991.371	.010	7 *b*	2	5022.05	.025	2 *N*
4 *s*	4991.993	.015	4 *N*	2	5022.30	.014	2 *N*
6 *s*	4992.757	.012	6	2	5022.79	.014	4 *N*
3	4993.62	.033	5	2	5023.064	.002	4 *N*
2	4994.17	.017	2	3 *s*	5023.499	.012	5
4 *s*	4994.809	.004	5 *N*	2	5024.12	.017	1
6 *s*	4995.465	.007	3	5 *s*	5024.592	.008	5
4 *s*	4995.914	.023	5 *N*	2	5024.95	.002	5
3 *s*	4996.193	.003	5	2	5025.54	.017	1
3 *s*	4996.544	.010	2	2	5025.816	.002	3
2	4997.28	.007	1 *N*	2	5026.29	.002	1
5 *s*	4997.824	.010	4 *vb*	2	5026.66	.011	2 *b N*
7 *s*	4998.805	.010	8	3	5027.19	.010	2 *N*
4	4999.471	.017	2	3	5027.52	.016	2 *N*
4 *s*	4999.993	.017	2	3	5028.426	.005	2 *N*
4	5000.917	.013	2	2	5028.775	002	2 *N*
3	5001.38	.015	2	3 *s*	5029.235	.013	2
2	5002.04	.013	2 *b*	2	5029.87	.004	6
2	5002.75	.011	0	2	5030.22	.010	1
5 *s*	5003.359	.014	4 *b*	3 *s*	5030.657	.011	3
2 *s*	5003.61	.021	3	2	5031.11	.060	0 haze

TABLE I—*Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5031.46	0.008	2 *N*	3	5059.47	0.017	1
2	5031.90	.012	1 *N*	4	5059.800	.014	2
2	5032.42	.013	3	3	5060.56	.006	2 *N*
3 *s*	5032.87	.020	3 *N*	6 *s*	5061.383	.011	5 *b*
2	5033.566	.001	2	2	5062.20	.002	1 *b N*
3 *s*	5033.89	.009	2 *N*	2	5062.89	.004	1 *b N*
4 *s*	5034.541	.009	3	2	5064.08	.027	1 *N*
2	5034.89	.012	3	2	5064.49	.024	3
3	5035.50	.031	3	3	5065.39	.025	3
3	5036.07	.014	3	4 *s*	5066.110	.010	4 *s*
3	5036.77	.023	4	3	5066.65	.017	2 *N*
2	5037.19	.009	0	3	5067.23	.034	1 *N*
3	5037.56	.021	1	2	5067.86	.014	1 *N*
5 *s*	5038.028	.014	5	2	5069.11	.053	2 *vb N*
2	5038.57	.010	2 *N*	2	5069.60	.021	2 *N*
2	5039.35	.030	2	2	5070.59	.003	2 *N*
3 *s*	5039.824	.017	5	2	5071.45	.020	3
2	5040.17	.034	2	2	5071.90	.033	0 *N*
3 *s*	5040.746	.009	4 *s*	3	5072.46	.016	3 *b N*
2	5041.28	.014	2	2	5073.29	.014	1
2	5041.56	.030	2	2	5073.61	.030	0
2	5042.46	.001	1 *vb d? N*	3	5073.99	.007	2
2	5043.48	.034	1 *b N*	2	5074.65	.015	2 *b N*
3	5044.38	.018	2	2	5075.38	.008	3
4 *s*	5045.061	.010	3	2	5076.08	.023	3
4 *s*	5045.500	.012	3	2	5076.54	.015	3
2	5046.02	.014	1 *N*	2	5077.06	.015	2
2	5046.62	.036	0	6 *s*	5077.434	.009	5
3 *s*	5047.22	.014	3	2	5078.01	.009	1
3 *s*	5047.78	.012	2	4 *s*	5078.543	.012	4
3	5048.24	.012	3	2	5079.08	.018	1
2	5048.94	.008	4	2	5079.57	.006	6 *s*
3	5049.33	.019	2	2	5080.39	.005	2
2	5049.68	.002	2 *N*	2	5080.78	.015	2
2	5050.05	.022	2 *N*	2	5081.69	.007	1 *b N*
2	5050.71	.003	3	2	5082.28	.008	1 *b N*
2	5051.01	.011	3	2	5082.83	.009	2
2	5051.48	.016	2	2	5083.50	.008	1 *b*
3	5051.87	.010	4	2	5084.15	.010	4
2	5052.33	.012	3	2	5084.78	.012	2
2	5052.65	.006	3	2	5085.62	.040	0
2	5053.15	.009	2 *N*	2	5086.25	.001	3
2	5053.650	.000	2 *N*	2	5086.95	.027	1
3 *s*	5054.21	.023	3	1	5087.22		2
2	5054.60	.015	2 *N*	2	5087.93	.035	2 *b N*
2	5055.18	.032	3	2	5088.72	.018	3 *vb d*
2	5055.59	.014	2 *N*	2	5089.53	.004	2
2	5056.36	.013	3	4 *s*	5090.416	.006	4
2	5056.93	.035	3	2	5091.10	.007	1
6 *s*	5057.519	.012	4 *b*	2	5091.58	.001	0
3	5058.08	.026	1	3	5092.17	.024	2 *N*
6 *s*	5058.647	.009	4 *b*	2	5092.86	.033	2 *N*

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5093.39	0.010	1	2	5122.13	0.025	1
4 *s*	5093.962	.004	3	2	5122.72	.010	1 *N*
2	5094.755	.003	3 *vb*	2	5123.38	.072	1 *b N*
2	5095.86	.028	4	2	5124.57	.002	2 *N*
2	5096.22	.025	1 haze	2	5125.11	.008	2 *N*
2	5096.68	.005	1 haze	2	5125.93	.014	1
3	5097.22	.017	2	2	5126.38	.038	0 *N*
3	5097.66	.022	2 *N*	3	5126.89	.015	3
3	5098.22	.009	2	3	5127.51	.012	2
2	5098.75	.005	2 *N*	2	5128.08	.027	3 *s*
2	5099.05	.025	2 *N*	2	5128.45	.003	1
2	5099.52	.008	1 *N*	3	5128.94	.008	3 *s*
2	5099.86	.011	1 *N*	3	5129.59	.013	2
3	5100.27	.026	2	3	5130.35	.022	2 *b N*
2	5100.77	.057	1 *N*	4	5131.327	.012	8
2	5101.12	.017	3	2	5131.95	.001	2 *N*
5 *s*	5101.85	.01'	3	4	5132.240	.014	2 *N*
2	5102.55	.035	1 *N*	2	5132.864	.001	1
3	5102.86	.018	2 *N*	5 *s*	5133.372	.013	4
2	5103.31	.040	0	3	5134.52	.021	2 *vb N*
2	5104.06	.023	2	4 *s*	5135.765	.015	5
3 *s*	5105.15	.024	4 *b*	5	5136.95	.023	3 *N*
2	5105.915	.002	3	2	5137.51	.025	0
3	5106.21	.015	4	5	5138.173	.012	3 *vb*
2	5107.26	.009	4 *b d?*	5	5139.15	.019	4 *b*
2	5108.33	.038	5	4	5139.81	.017	3
2	5108.77	.006	0	3	5140.61	.026	3 *b N*
2	5109.15	.008	0	4	5141.08	.017	2 *N*
2	5109.69	.002	4	3	5141.71	.012	2
2	5110.07	.013	4	2	5142.45	.026	2 *N*
2	5110.61	.005	2	2	5142.75	.033	2 *N*
2	5111.13	.023	1 *N*	5	5143.283	.014	2
2	5111.54	.022	2 *N*	2	5143.69	.027	1 *N*
2	5112.11	.004	2	5	5144.372	.013	4 *vb*
2	5112.66	.030	1	2	5145.32	.004	0
2	5113.08	.016	2	6	5146.027	.010	4 *b*
2	5113.49	.014	2	6	5146.741	.015	3
2	5113.87	.002	1	6	5147.597	.009	4 *b*
2	5114.24	.006	1	2	5148.69	.015	0
2	5114.66	.005	1	7	5149.531	.010	2 *N*
2	5114.97	.004	1	3	5150.56	.010	1
2	5115.81	.018	1 *N*	2	5151.12	.006	4
3	5116.22	.004	1 *N*	2	5151.34	.020	4
3	5116.60	.005	1 *N*	5	5151.81	.019	0
2	5117.40	.036	4 *b*	6	5152.421	.008	4
2	5117.85	.008	4 *b*	6	5153.042	.015	3
2	5118.69	.024	0 *N*	4	5153.712	.012	2
2	5119.24	.011	4	5	5154.22	.018	2 *N*
2	5119.78	.007	4	4	5154.955	.013	4 *N*
2	5120.45	.011	0	4	5155.38	.021	2 *b N*
2	5121.07	.009	4	2	5156.33	.022	2 *b*
2	5121.46	.067	0 *N*	5	5157.059	.012	4 *N*

TABLE I—*Continued.*

n	Wave-length	Mean error	Intensity and character
5	5157.553	0.013	3 *N*
3	5158.19	.027	1
4	5158.52	.019	4
6	5159.113	.011	4
2	5159.75	.006	0
3	5160.53	.013	0
3	5161.20	.022	1 *N*
Chlorine at atmospheric pressure			
3	5165.584	.015	2
3	5165.987	.008	2
4	5166.396	.005	2
5	5167.255	.007	5 *vb*
11	5168.426	.006	6 *s*
3	5168.821	.013	1 *N*
3	5169.733	.008	5 *b*
3	5170.998	.015	2 *vb N*
4	5172.014	.013	3
3	5172.419	.005	3
3	5172.91	.017	0
4	5173.437	.013	2
4	5173.946	.010	2
4	5174.741	.016	1 *vb N*
4	5175.499	.008	4 *s*
3	5176.142	.008	4
2	5177.109	.003	3
3	5177.615	.009	2 *N*
3	5178.30	.029	0
4	5178.780	.015	6 broadened on red side
3	5179.197	.031	0 haze
3	5179.692	.029	0 haze
4	5180.550	.019	3 *b N* broadened on red side
1	5181.101		0 *N*
3	5181.619	.007	0
3	5182.379	.018	3 *b N* broadened on red side
3	5182.927	.010	0 *N*
2	5183.408	.003	0 *N*
3	5184.244	.022	3 *b N* broadened on red side
3	5184.555	.014	0
4	5184.999	.024	1
4	5185.579	.006	1
4	5186.142	.011	8
3	5186.517	.007	0
3	5187.271	.017	2 *b*
3	5188.158	.021	3 *b*
4	5189.028	.019	1 *b*

n	Wave-length	Mean error	Intensity and character
4	5161.67	0.026	2
5	5162.37	.021	1 *N*
6	5162.99	.016	7
3	5163.40	.011	0
5	5163.948	.010	3
5	5164.954	.015	3
Chlorine at a pressure of 2½ atmospheres			
3	5165.596	.012	3
4	5166.002	.016	3
2	5166.428	.015	3
5	5167.268	.010	10 *vb*
8	5168.427	.005	9 *s*
6	5169.727	.008	10 *b*
4	5171.008	.022	5 *b*
5	5172.039	.007	3
4	5172.461	.013	3
6	5173.433	.008	2
6	5173.947	.013	2
4	5174.756	.018	2 *b*
5	5175.515	.015	5 *s*
6	5176.149	.008	5
4	5177.142	.014	4
3	5177.618	.015	4
6	5178.818	.005	7 *b*
3	5179.375	.027	1 band
4	5180.612	.010	5 *b*
3	5181.074	.022	1 *N*
3	5181.631	.009	1
6	5182.413	.012	7
1	5182.914		1 *N*
1	5183.366		1 *N*
6	5184.300	.013	8
4	5185.014	.020	1
6	5186.181	.006	10
1	5186.528		0
3	5187.328	.020	2 *b*
3	5188.122	.012	6 *b*
6	5189.024	.016	2

TABLE I—*Continued.*

Chlorine at atmospheric pressure				Chlorine at a pressure of 2½ atmospheres			
n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
3	5189.862	0.026	1 *N*	3	5189.894	0.013	1 *N*
3	5190.314	.004	1 *N*	4	5190.285	.025	1 *N*
2	5190.816	.013	0 *N*	4	5190.826	.030	0 *N*
3	5191.395	.005	1	4	5191.495	.016	2
3	5191.964	.007	1	5	5191.928	.015	2
3	5192.533	.003	3	6	5192.536	.011	4
3	5193.540	.011	2 *b*	5	5193.512	.010	3 *b*
2	5194.158	.013	2	4	5194.154	.012	2
4	5194.706	.013	5	5	5194.751	.014	8
2	5195.444	.006	2	4	5195.452	.014	2
3	5196.220	.018	5 *s*	6	5196.219	.011	6 *s*
2	5196.916	.031	3 *N*	6	5196.913	.017	4 *N*
2	5197.320	.010	1 *N*	2	5197.340	.005	1 *N*
2	5197.839	.008	1	3	5197.906	.011	2
2	5198.314	.003	1 *N*	2	5198.300	.015	1 *N*
3	5198.832	.027	1 *s*	6	5198.841	.011	7 *s*
				3	5199.465	.019	3
3	5199.836	.009	3 *N*	4	5199.854	.011	6
3	5200.625	.018	2 *N*	1	5200.648		4
3	5201.076	.014	2 *N*	1	5201.012		4
3	5202.108	.017	3 *vb*	3	5202.073	.018	6 *vb*
3	5203.150	.010	4 *b*	3	5203.166	.015	8 *b*
2	5204.414	.020	4 *b*	4	5204.407	.010	10 *b*
3	5205.722	.018	2 *vb*	4	5205.729	.026	5 *b*
3	5207.113	.043	2 *vb*	4	5207.100	.005	5 *vb*
3	5207.915	.013	1	4	5207.942	.011	2
				3	5208.479	.040	0
3	5209.423	.020	2	3	5209.440	.029	3
2	5210.188	.014	1 *N*	3	5210.186	.010	2 *N*
				4	5210.754	.018	2 *b N*
2	5211.677	.043	1 *N*	4	5211.703	.016	2
3	5212.537	.017	0 *N*	3	5212.355	.019	2
1	5213.13		1 *N*	4	5213.348	.014	3 *bd N*
2	5213.491	.006	1 *N*				
2	5214.998	.058	1 *N*	2	5214.051	.046	2 *b N*
2	5215.896	.028	1 *N*	4	5215.892	.019	2
2	5216.886	.050	2 *b N*	4	5216.917	.009	5 *b*
1	5217.899		1	4	5217.874	.012	2
2	5218.783	.009	2 *b*	4	5218.755	.017	5 *b*

Chlorine at 2½ Atmospheres Pressure.

6	5219.715	.016	1	5	5227.316	.013	2
5	5220.696	.010	10	5	5227.73	.016	1 *N*
6	5221.72	.015	2	5	5228.63	.025	3
4	5222.73	.019	5 *b*	5	5229.105	.010	2
4	5223.87	.008	1 *b N*	5	5230.051	.010	3 *b N*
4	5224.62	.035	3 *vb N*	5	5230.61	.025	1 *N*
4	5225.40	.017	1	5	5231.16	.025	1 *N*
5	5226.37	.021	3 *vb*				

TABLE I — *Continued*

Chlorine at 2½ atmospheres pressure.

n	Wave-length	Mean error	Intensity and character	n	Wave-length	Mean error	Intensity and character
3	5231.55	0.028	0	4	5269.44	0.020	1
7	5232.12	.02	2	4	5270.09	.021	1 *N*
5	5233.37	.010	6 broadened on red side	4	5270.808	.009	2 *N*
				5	5271.408	.012	2 *N*
2	5233.74	.025	2	2	5272.20	.008	0
5	5234.693	.006	7 *s*	4	5273.04	.023	3 *N*
5	5236.324	.011	4 *b*	4	5273.60	.023	0
5	5237.309	.006	5	4	5274.27	.026	0
4	5238.16	.018	4 *b d* ?	3	5274.67	.040	0 *N*
7	5239.05	.014	1	5	5275.27	.020	2 *N*
4	5240.15	.024	2 *N*	5	5276.05	.022	1
5	5240.55	.014	2 *N*	5	5276.653	.015	4
3	5241.41	.018	0	6	5277.342	.014	4 *s*
6	5241.697	.019	3 *b*	7	5278.040	.008	4
6	5242.518	.011	2	7	5278.962	.013	1
5	5242.939	.014	3	4	5279.80	.015	2 *b*
5	5244.151	.029	1 *b N*	4	5280.38	.019	2 *N*
7	5245.110	.010	3 *s*	5	5280.981	.006	2 *N*
6	5245.673	.012	2 *s*	4	5281.32	.024	1 *N*
5	5246.47	.028	1 *N*	4	5282.091	.011	3
5	5247.13	.022	1 *N*	5	5282.549	.012	2
6	5247.936	.010	3	4	5283.249	.012	2
5	5248.635	.009	5 *b*	4	5283.70	.015	3
5	5249.527	.014	1	4	5284.39	.020	2 *N*
6	5250.061	.013	4	4	5284.86	.018	2 *N*
5	5250.72	.019	0	3	5285.63	.010	0
5	5251.13	.032	1	3	5286.22	.014	1
4	5251.72	.016	2	4	5286.94	.056	0 *N*
5	5252.26	.015	1	4	5287.53	.023	2 *N*
5	5253.282	.008	3 broadened on red side	4	5288.25	.023	1
				5	5288.898	.012	3
5	5254.606	.016	3 *b*	5	5289.62	.019	2
5	5256.26	.023	1	5	5290.342	.007	5 *s*
5	5257.08	.019	3	5	5291.131	.008	1
3	5257.41	.005	1	6	5291.863	.008	4
6	5258.166	.015	4 *s*	5	5292.701	.009	1
5	5258.882	.013	4 *b*	4	5293.522	.010	4
6	5260.088	.009	4	4	5294.48	.020	1 *b*
7	5260.584	.009	4	5	5295.268	.012	4
3	5261.79	.024	1 *N*	5	5296.11	.022	0
5	5262.068	.010	3	6	5296.97	.016	4
4	5262.649	.012	2	5	5297.92	.019	1 *b*
5	5263.376	.007	3	4	5298.75	.017	1 *b*
5	5263.82	.023	2 *N*	5	5299.60	.014	2
4	5264.77	.040	1 *vb N*	4	5300.65	.020	4 *b N*
4	5265.73	.037	0	3	5301.50	.015	1
5	5266.310	.010	1	3	5302.48	.018	1 *b N*
4	5266.96	.023	2 *N*	3	5303.02	.064	1 *b N*
4	5267.46	.016	2 *N*	3	5304.69	.018	1 band
4	5268.517	.006	2 *N*	3	5306.90	.024	1 *N*
4	5268.98	.022	2 *N*	3	5307.49	.055	1 *vb N*

TABLE I — *Continued.*

Chlorine at 2½ atmospheres pressure

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5307.90	0.046	0 *N*	4	5346.70	0.021	2
3	5308.43	.027	0 *N*	4	5347.40	.016	1
4	5308.99	.017	1	4	5347.960	.006	1
4	5309.62	.017	0	4	5348.702	.013	2
3	5310.11	.018	2	4	5349.556	.005	1
5	5310.958	.013	2 *s*	4	5350.48	.043	0 *N*
4	5311.718	.013	3 *s*	4	5351.63	.021	1 *N*
4	5312.57	.033	0 *N*	4	5352.650	.011	1 *b*
4	5313.42	.025	1 *N*	4	5353.878	.014	1 *b*
4	5314.13	.016	2	4	5355.04	.021	1 *b*
4	5315.074	.005	1	4	5355.98	.022	1
4	5315.63	.026	1	5	5356.76	.016	1
2	5316.36	.043	0	3	5357.29	.017	1
3	5316.66	.011	1	4	5357.52	.022	1
2	5317.28	.005	0	3	5358.25	.020	1 *N d*
4	5317.968	.013	1	4	5359.02	.018	1 *N*
3	5318.44	.029	0	5	5359.476	.007	1
4	5319.17	.014	1	4	5360.38	.016	2 *vb*
3	5319.78	.016	1	5	5361.88	.022	1 *vb N*
3	5320.55	.025	3	5	5363.58	.032	1 *b N*
3	5320.89	.020	3	5	5365.03	.010	1
4	5322.19	.017	3 *b d?*	4	5366.05	.009	0
2	5322.76	.017	0	5	5366.71	.021	1
4	5323.608	.010	4 *b*	3	5367.43	.015	0
4	5324.42	.014	0	2	5367.98	.003	0
4	5325.18	.018	1	4	5368.575	.006	1
4	5326.721	.010	3	2	5369.667	.012	0
4	5327 49	.023	1 *b*	4	5370.18	.022	0
4	5328.438	.014	4	4	5370.64	.053	1 *N*
4	5330.07	.016	5 *b*	5	5371.21	.025	0 *N*
3	5330.65	.017	0	4	5372.03	.018	2
4	5331.909	.009	4 *s*	5	5372.61	.012	2 *b*
3	5332.58	.021	0	3	5373.44	.014	1
4	5333.24	.019	0	4	5374.30	.015	2 *b*
6	5333.638	.011	5 *s*	5	5375.28	.017	1
4	5334.65	.031	0 *N*	5	5376.25	.019	1
4	5335.224	.014	1	5	5377.10	.021	1
4	5335.74	.023	1 *N*	3	5378.29	.063	1 *vb N*
4	5336.59	.015	0	5	5380.49	.022	1 *b N*
4	5337.80	.025	2 *b N*	3	5381.98	.033	0 *N*
3	5338.60	.034	0	4	5382.92	.014	0
4	5339.21	.042	0	3	5383.52	020	1
4	5339.90	.017	1 *N*	3	5384.55	.022	2 *b*
4	5340.82	.049	0 *N*	2	5385.74	.011	0
4	5341.49	.056	0 *N*	2	5386.83	.030	0
4	5342.27	.018	2 *b d N*	3	5387.48	.016	1 *b*
5	5343.18	.015	1	2	5387.93	.028	1 *N*
2	5343.68	.040	0 *N*	2	5388.71	.008	0 *N*
2	5344.42	.063	0 *N*	3	5389.19	.051	0 *N*
4	5344.88	.022	0 *N*	2	5389.85	.008	0
4	5346.02	.021	2	3	5390.36	.028	1

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5391.22	0.044	0 *N*	1	5423.15		0 *b N*
3	5392.13	.022	1 *b N*	1	5425.12		0
2	5393.88	.063	0 *vb N*	1	5425.87		0 *N*
3	5395.39	.042	1 *b N*	1	5426.71		0 *N*
3	5396.74	.011	1	1	5427.34		1
2	5398.03	.100	1 *b N*	1	5428.10		1
3	5399.50	.012	0 *b*	1	5429.79		1
2	5401.09	.032	0	1	5432.27		0
2	5402.37	.026	0 *N*	1	5433.95		0
2	5403.62	.023	0 *b N*	1	5434.44		1
2	5405.09	.011	0 *b N*	2	5435.46	.013	1 *b*
2	5405.69	.001	1	2	5436.98	.004	1 *b*
2	5406.73	.020	1	2	5438.21	.018	1 *b*
2	5407.36	.015	1 *N*	2	5438.86	.015	0
2	5408.39	.057	0	2	5439.56	.011	0 *b*
2	5409.02	.006	1	2	5440.77	.005	0 *b*
2	5409.74	.023	0	2	5442.09	.064	0
2	5410.22	.026	0	2	5442.77	.005	1
2	5410.85	.035	0	2	5443.46	.010	0
2	5412.04	.042	1 *N*	2	5444.14	.007	0
2	5412.75	.047	1 *N*	1	5444.67		0
2	5414.65	.053	0 *N*	1	5445.40		0
2	5416.41	.100	0 *b* band	2	5448.42	.005	0
1	5418.37		0 band	2	5449.26	.018	0
1	5420.31		0 band	2	5450.05	.002	0

The line spectrum.—The lines of the absorption spectrum of one meter of chlorine at atmospheric pressure begin at about λ4799 and extend to λ5350; the first lines in the blue are very faint, as are also, in general, those in the yellow above λ5200. Those of maximum intensity lie nearer to the blue end than to the yellow. Few of the lines are sharp, the greater number have ill-defined edges, and not many are very broad. There are numerous pairs of lines, and some groups of three lines; but there is no apparent law in the distribution of these groupings.

The spectrum, especially in the first order, presents to the eye a fluted appearance, or recurring maxima and minima of absorption, which becomes more distinct as the quantity of chlorine is increased. The flutings are narrow at the point where the lines begin in the blue and become gradually broader on going towards the red. Examined under the microscope

they do not appear to have heads like those of the carbon bands, nor have they any visibly regular grouping; but the lines in the part of the band which gives the impression of greatest absorption to the eye are somewhat closer together than those in the rest of the band. The lines have all about the same width and intensity. It is possible that this fluted appearance may be due in great part to narrow patches of general absorption superposed on the line spectrum.

The general absorption spectrum.—The general absorption spectrum of chlorine consists of a broad band in the violet which was early discovered and which has been studied by Liveing and Dewar. There are also, perhaps, some smaller patches of absorption superposed on the region containing the line spectrum and giving to it a fluted appearance, as described above. The width of the violet band varies with the pressure and length of the column of chlorine used, and some measurements of it will be given later.

The effect of pressure on the general absorption spectrum.— It is generally considered that the absorption band spectrum of a gas arises from the line of spectrum as the result of increasing the density of the gas in question. Hasselberg,[1] describing the spectrum of nitrogen peroxide, says, that with increase of density new lines appear, not previously visible, and that the old ones become stronger, until together they form broad bands; finally, through increase in the number, blackness and width of the lines, the absorption becomes total. In the case of iodine, he says that with increase of density or of length of column, all the lines increase in intensity and width, and that at the same time a continuous absorption is developed, beginning at the violet end of each fluting and extending towards the red; and that finally the absorption becomes total. Konen[2] describes the same effect on the spectrum of iodine. In emission spectra it is generally considered that a line spectrum may be changed into a continuous spectrum by sufficiently increasing the pressure. It

[1] *Mém. de l'Acad. de St. Petersb.* [7], **26**, No. 4, 17, 1878; **36**, No. 17, 8, 1889.

[2] *Wied. Ann.*, **65**, 285, 1898.

might, therefore, be thought possible to change from a continuous absorption spectrum to a line spectrum by decreasing the pressure. This might take place in two ways: either the continuous absorption would break up into a number of lines scattered over, approximately, the same region that the general absorption occupied, thus being the reverse of what happens in the visible spectrum of iodine and nitrogen peroxide when the density is increased; or, the edges of the general absorption might recede until only one narrow absorption band or line would be left.

Some experiments were made to find what effect the decrease of pressure would have on the general absorption band in the spectrum of chlorine.

The tube 1.37 m long being exhausted, chlorine was let in until the total pressure, as measured by a manometer attached, was 30 cm of mercury in one case, and 10 cm and 5 cm in other cases. Further, the steel tube 33.2 cm long was exhausted and filled with chlorine at 10 cm pressure. Photographs were made of the absorption spectrum in each case. In the ultra-violet part the tube 80 cm long fitted with quartz ends was used with the gas at pressures of an atmosphere, half an atmosphere, and about 8 cm. In no case was any trace of a breaking up into lines found. The experiments were not entirely conclusive in this respect in the region of the ultra-violet below the absorption band, for the arc spectrum in this part is not sufficiently continuous to make the decision final as to the non-existence of absorption lines, and the difficulties of photographing became too great beyond $\lambda 2500$, owing to the increase of the diffuse light reflected from the grating. With the chlorine at atmospheric pressure the general absorption extends to $\lambda 4700$; at 5 cm it has receded to $\lambda 3800$. In the region $\lambda 4700$–$\lambda 3800$ careful search could, therefore, be made for lines; but none were found. The total effect of a decrease of the pressure of chlorine was a diminishing of the width of the absorption band; hence we may consider the general absorption as a broadened line. If we could sufficiently decrease the pressure we might

expect to find this line. It broadens much more rapidly on the less refrangible than on the more refrangible side with increase of pressure, and finally extends into the region of the absorption lines. The same effect on the width of the absorption band may be obtained by decreasing the length of the column of chlorine, and leaving the pressure unchanged as by decreasing the pressure with a given length of column.

The edges of the band are not sharply defined. So that determinations of its width can have only relative accuracy. The following are some measurements for different pressures of chlorine, which are reduced to the equivalent columns at atmospheric pressure.

TABLE II.

Equivalent length of column at atmospheric pressure	Width of absorption band
272 cm.	λ4990 to ....
103	λ4700 " ....
60	λ4650 " λ2599
40	λ4420 " λ2630
14	λ4115 " λ2750
7	λ3850 " λ2881
3·5	λ3718 " ....

The effect of pressure on the line spectrum.—Photographs were taken of the visible line spectrum with the 1.37 m tube filled at 30 cm and 10 cm pressure. In the first case the lines in the blue and green-blue appeared unchanged in position and perhaps a little sharper than when chlorine at atmospheric pressure was used, but the lines in the green-yellow were too faint to be measured. In the second case, with 10 cm pressure, all the lines had become faint.

In order to study the effect of increasing the pressure, a new steel tube 1.36 m long was made, fitted with caps the openings in which were 4.9 cm in diameter. The end glass plates were very carefully ground to the ends of the tube; but notwithstanding the care taken, great difficulty was experienced in using the tube. It held sufficiently well, however, for pressures up to 2½ atmospheres, that is, when the partial pressure of the

chlorine was about 2 atmospheres, and it was used at this pressure. The spectrum so obtained showed no new lines in the part where they had been measurable before, but the old ones were much more intense. The broadening of the lines was slight and not nearly so noticeable as their marked increase in intensity. Farther up in the yellow new lines became visible; at the same time the general absorption advanced up to λ4990, so that those lines which had been previously the strongest and sharpest were no longer visible. This spreading out of the general absorption did not appear to come from broadening of the lines, for as far as lines could be seen, which was right down to the edge of the general absorption, they remained hardly less sharp and distinct than before. This absorption, then, is rather to be considered the extension of the general absorption band from the violet up into the green, and the lines become invisible because of the greater intensity of the general absorption.

It seems as if we must consider that there are two absorption spectra here, each of which is separate and distinct from the other. The one is a line absorption, which persists always, though in certain cases it may be invisible, because it is too faint, or, on the other hand, because it is covered over by the general absorption. The other is a general absorption which consists of a broad band in the violet end of the spectrum, and possibly also of little patches, which lend, partly, the appearance of channelings to the line spectrum. With increase of density the lines become stronger, and are unchanged in position; but the general absorption broadens out very much, especially towards the less refrangible end, until it engulfs the lines and renders them no longer visible. The presence of two spectra might be explained by the different action which different groupings of the constituents of the gas may have on light radiations. One could think of the general absorption as due to molecule-complexes, and of the line absorption as due to simpler combinations of the separate atoms. An analogy in emission spectra is the spectrum of the arc light, in which brilliant lines are seen on a continuous bright background, like the

superposition of a line spectrum on a continuous one. In the case with which we are dealing it is not to be expected that we could see the absorption lines on the black background with the light used.

As the question of the fixed position of the lines under changes of pressure is of interest, measurements are given in Table I on the lines from λ5165 to λ5218 for chlorine at atmospheric pressure and at two and a half atmospheres pressure. A comparison shows that, except for some lines broadened on the red side, the displacement is, in general, smaller than the error of measurement, and is sometimes toward the blue end and sometimes toward the red. The conclusion is that the apparent differences are due to errors of measurement and differences in setting. It is generally accepted that within moderate limits an increase of temperature has the same effect on the absorption spectra of gases as an increase in pressure. The present experiments have all been made at room temperatures.

COMPARISON OF CHLORINE SPECTRA.

Morren's description of the general appearance of the chlorine absorption spectrum agrees with the results of the present experiments. The region over which lines have been observed has been extended, although the quantity of chlorine has been smaller than that used by Morren. This may be explained by the fact that his observations were made directly with the eye. The truth of the remarks of Gernez concerning the chlorine spectrum is not borne out by the results now found, since, according to the present investigation, 4.68 meters of chlorine (the amount used by Gernez) would absorb a large part of the visible spectrum, and would not give a spectrum extending into the "violet," as his statement reads. There are no measurements given in either case with which to compare the present ones.

The general absorption of 15 mm of liquid chlorine, as given by Gänge, corresponds roughly to that of a meter of chlorine gas at two and a half atmospheres pressure, as the numbers given above for the beginning of the total absorption show.

The results of the experiments here made on the total absorption band in the violet agree with those obtained by Liveing and Dewar. Strict comparison of the measurements on the width of the band is impossible, as Liveing and Dewar do not give details concerning the amounts of chlorine used.

It was not to be expected that the chlorine absorption spectrum would agree with its known emission spectrum. The phenomenon of reversed lines shows that bodies which emit light of certain wave-lengths will also absorb light of those same wave-lengths; and through certain ranges it has been shown that the absorption or emission is independent of the temperature, provided the general mode of vibration remains unaltered. If, however, the mode of vibration changes, owing, perhaps, to some change in the molecular or atomic grouping, the emission at one temperature is not the same as the absorption or emission at another. In the case of iodine, comparison has been made by Konen[1] between the absorption spectrum and the various emission spectra; he states that the absorption spectrum corresponds to the band spectrum of vacuum tubes, to the flame spectrum, and to the glow spectrum obtained by heating the gas in closed vessels.

In the present case the only known chlorine emission spectrum is a line spectrum. The lines lie between $\lambda 3276$ and $\lambda 6758$, but the majority are at the violet end, which region is covered in the absorption spectrum of a meter of chlorine by a broad band. In the region which contains lines in both emission and absorption spectra, coincidences were looked for. A large number of lines are nearly coincident, as will be seen from the following table, which contains the wave-lengths and intensities of the emission lines as given by Eder and Valenta,[2] together with the wave-lengths and intensities of the lines lying nearest to them in the absorption spectrum. Except for a few cases the differences are too great to be due to errors in measurement and the relative intensities are altogether different.

[1] *Loc. cit.*, p. 259. [2] *Loc cit.*, p. 8.

TABLE III.

λ_c	I_c	λ_a	I_a	λ_c	I_c	λ_a	I_a
4810.194	9	4809.949	1	5158.9	½	5159.113	4
4819.628	9	4820.059	2	5162.50	1	5162.37	1
4896.905	5	4896.888	2	5173.4	1	5173.43	2
4904.905	4	4904.767	1	5176.0	½	5176.14	4
4917.870	2	4917.943	7	5189.74	1	5189.86	1
4924.90	1	4924.86	3	5193.6	½	5193.54	2
4927.3	½	4927.213	3	5218.07	3	5217.87	2
4943.1	½	4942.905	4	5221.48	4	5221.72	2
4970.3	1	4970.52	6	5285.8	½	5285.63	0
4995.7	1	4995.914	5	5392.300	4	5392.13	1
5078.361	4	5078.543	4	5423.441	6	5423.15	0
5083.59	1	5083.50	1	5423.703	2		
5089.6	½	5089.53	2	5443.587	5	5443.46	0
5099.36	1	5099.53	1	5444.412	3	5444.14	0
5103.18	4	5102.86	2	5445.12	1	5445.40	0
5113.3	1	5113.08	2				

A comparison of the absorption spectra of iodine and bromine with that of chlorine shows that with decreasing atomic weight, increasing amounts of the gas must be used to render visible and distinct the absorption lines. Hasselberg obtained the absorption spectrum of iodine using a column of 10 cm of the vapor, and that of bromine by using a 75 cm column, whereas 137 cm of chlorine was not more than sufficient for the purpose. The given iodine spectrum extends a little farther on the red side than the bromine spectrum, and much farther than that of chlorine even for a 136 cm column at two atmospheres pressure; that is, the lines of this group shift towards the red with increasing atomic weight. This is analogous to the behavior of the emission spectra of any one group of elements, as shown by Kayser and Runge. Hasselberg measured about 3000 lines in the iodine spectrum, and about 2500 in the bromine spectrum; in the spectrum of chlorine only about 1000 have been observed. This number would probably have been increased if still greater amounts of chlorine had been used.

The lines of the iodine spectrum are, according to Hasselberg, fully as sharp and distinct as the solar lines; those of bromine, it is to be inferred, are not so good; and certainly the

chlorine lines are much less sharp and well defined than those of the solar spectrum.

As previously mentioned, the earlier investigators observed a similarity in the appearance of the iodine and bromine spectra, but under the dispersion now used, the lines which they observed are seen to be bands composed of a number of lines. These bands appear as channelings in the spectra and continue to make the two spectra appear somewhat similar. These, as already noted, are not absent from the chlorine spectrum, but again iodine has them most distinctly, and bromine and chlorine in diminishing distinctness. If one used the proper densities in all three cases the three spectra could doubtless be made to assume a very similar appearance.

SUMMARY OF RESULTS.

The complete absorption spectrum of chlorine at ordinary temperatures consists of a very broad total absorption band in the violet region, of a line absorption in the blue, green and yellow, and of transparency in the visible red.

The lines do not coincide with the known line emission spectrum of chlorine.

With increase of pressure the absorption band in the violet broadens out rapidly on the less refrangible side, more slowly on the more refrangible side. Decrease of pressure does not break it up into lines.

The total absorption band behaves as if it were a separate absorption spectrum from the line spectrum.

Increase of pressure increases the intensity of the line spectrum greatly and causes new lines towards the red to become visible.

The absorption lines of the elements of the halogen group shift toward the red with increasing atomic weight.

The number and sharpness of the absorption lines of the elements of the halogen group increase with increasing atomic weight.

The amount of gas necessary to render visible the absorption

lines of the elements of the halogen group decreases with increasing atomic weight.

In conclusion, it is a pleasure to me to express my deep gratitude to Professor A. Stanley MacKenzie under whose direction this investigation has been carried out, for the constant encouragement and assistance which he has given me during the course of this work.

PHYSICAL LABORATORY,
BRYN MAWR COLLEGE,
June 1901.

SOME PROPERTIES OF THE ELECTRIC SPARK AND ITS SPECTRUM.

By CHARLES C. SCHENCK.

I.

IT is well known that in many spectra the lines are not arranged in haphazard order, and many attempts have been made to divide lines into different groups according to their characteristic behavior, and to associate together lines in the spectra of closely related elements. Professor Ames[1] was the first to point out the intimate connection between certain lines in the arc spectrum of zinc and cadmium, thus determining the so-called homologous lines, and Kayser and Runge have since succeeded in dividing the chief lines in the arc spectra of many elements into their well-known principal, and first and second subordinates series.

The object of the first, or preliminary, section of this paper is to divide the principal lines in the spark spectrum of cadmium into three groups, each having characteristic properties peculiar to itself.

Kirchhoff[2] showed in 1861, and Thalen[3] in 1866, that the spark spectra of certain elements could be transformed into spectra closely resembling the simple flame spectra by inserting a wet string in the circuit containing the Leyden jar and the spark gap, so as to increase its resistance, or by causing the spark discharge to pass through the coils of an electro-magnet, thereby increasing the self-induction.

Hemsalech[4] has also investigated some of the general effects produced in spark spectra by inserting a self-induction in the discharge circuit from a condenser. He has not investigated the ultra-violet region, however, and has confined his attention to the statement of certain general effects observed. He has

[1] *Phil. Mag.* (5) 30, 1890.

[2] *Abhandlungen der K. Acad. Berlin*, 1861, p. 73.

[3] *Annuaire*, Upsala, 1866.

[4] *Jour. de Phys.*, December 1899.

also recently proposed[1] a division of the lines of spark spectra into groups, which does not quite agree, however, with the classification proposed in this paper, as it does not include any of the lines of Group C, mentioned below.

The division of the lines of the cadmium spark spectrum into three groups followed from a detailed study of the changes produced in the spectrum when the period of the condenser was varied by increasing the self-induction.

APPARATUS.

The spark was produced by a 110-volt alternating current, frequency 133 complete periods per second, which was stepped up to about 600 volts and put through the primary of a large induction coil, the potential of whose secondary was raised sufficiently to give a spark one centimeter long. The capacity consisted of six gallon jars connected in parallel, with a total measured capacity of 0.016 microfarads. The 110-volt current was regulated by a suitable resistance so as to give the best spark conditions for the given capacity, *i. e.*, a very noisy spark which should not heat the terminals to incandescence. If the current was too large the poles became very hot, the spark was less noisy, and, as was found later, the spectrum was not the same as with a noisy spark. The best spark was obtained when the 110-volt current was about twelve amperes, and the 600-volt current which passed through the primary of the induction coil was then about one ampere. The spark length varied from 6 to 8 millimeters. With the first-named length, the sparks followed one another with considerable regularity at the rate of 266 per second, and produced a fairly good musical tone, whose pitch was nearly that of middle C. When the terminals were pulled farther apart the regularity ceased, but again appeared at a spark length of about 8 millimeters, when the tone was an octave lower than the first.

The period of the condenser, when the wires connecting it to the spark gap were as short as possible, was found later by photographing the image of the spark by means of a revolving

[1] *Comptes Rendus*, April 22, 1901, p. 959.

mirror and measuring the separation of the oscillations on the photographic plate. Its value was 1.3×10^{-6} seconds. It should be added that each spark consisted of about ten or twelve complete oscillations.

The spectrum was photographed with the large concave grating of 21 feet radius. Some photographs were also taken by means of a small concave grating of 6 feet radius. Some plates of zinc and magnesium were taken for purposes of comparison.

RESULTS.

An examination of the cadmium plates showed the existence of about 143 lines in the ultra-violet, extending from λ 2100 to λ 3700, which have the following characteristic properties:

1. They have a breadth of ⅓ Ångström unit and their edges are hazy. They resemble air-lines somewhat, but they are not air-lines, being absent from the spark spectra of zinc, magnesium, and iron.

2. They extend only about 2 mm out from the poles toward the center of the spark, while the rest of the lines extend clear across the spark gap, with a spark 8 mm long.

3. When the spark length was 5 mm, and the period of the condenser was increased 13 times, *i. e.*, to 17×10^{-6} seconds, by throwing in self-induction, they disappeared from the spectrum, while the other metallic lines were practically unaffected. The period of the condenser was found by the rotating mirror as before, and the number of oscillations for each spark was nearly the same as before, *i. e.*, about 12.

4. They are absent from the arc spectrum, as given by Kayser and Runge and as photographed in this laboratory.

5. None of them are reversed.

These lines constitute the first group (C). Thirty-eight of them situated toward the red end are more hazy than the others, some of them being more than twice as broad, although in all other respects they are similar. Hence I have put them into a sub-group by themselves.

It is interesting to note here that the spark spectrum of zinc has a similar group of lines, while that of magnesium has not.

The second group of lines, (B), includes most of the remainder of the lines known as "spark lines," that is, lines either absent from or else very weak in the spectrum of the arc in air, but prominent in the spark. They have the following characteristics:

1. None of them are reversed.

2. When the period of the condenser was increased about 58 times, *i. e.*, to 75×10^{-6} seconds, some of them disappear and the others shorten up close to the poles, while the rest of the metallic lines extend uniformly across the spark gap. A few of the lines of Group B do extend clear across the spark gap, but they are strong close to the poles only and very weak throughout the center of the spark.

Under these conditions the number of oscillations of the condenser was 16 or 18, somewhat greater than before. The period was obtained in two ways: by photographing the spark with the rotating mirror, and by measuring approximately the self-induction of the coil, *i. e.*, 0.0093 henries and using the formula $T = 2\pi\sqrt{LC}$. The two values agreed to within 3 per cent.

The lines of the third group, (A), are the so-called arc lines. They include most of the lines common to both spark and arc. Some of them, as λ 4413, are extremely weak or absent altogether in the spark and strong in the arc. They form thus a spectrum simpler than that of the arc, and the effect of a self-induction is to make the spectrum of this group more complicated, and approach that of the arc. An examination of my plates showed that the scale of relative intensities among these lines is much closer to that of the same lines in the arc, when the period of the condenser is 75×10^{-6} than when it is 1.3×10^{-6}. In fact, with the period 75×10^{-6}, judging from the relative intensities of the lines, it might be said, figuratively, that I had gotten about "half-way" from the spark to the arc.

These lines possess the characteristic that they extend clear across the spark gap when the period of the condenser is great enough (75×10^{-6}) to cause the lines of Group B to shorten up close to the poles. There is scarcely any doubt that they

are due to luminous metallic vapors which fill up the entire spark gap, while the lines of Group B are due to a different phenomenon which will be brought out in the second part of this paper.

Now, since this spectrum (Group A) becomes more complicated, especially in the ultra-violet, as we pass from the spark spectrum toward the arc spectrum by increasing the period of the condenser, it seems probable that the temperature of the metallic vapors in the arc is higher than the average temperature of the vapors in the spark, and that one effect of self-induction is to raise the average temperature of the metallic vapors in the spark. By average temperature I mean a time average, taken throughout the interval during which the metallic vapors remain luminous in the spark. There are other reasons for this conjecture. When the duration of the entire discharge is increased 50 to 60 times, there is more time for the vapors to become heated. Again, it is well known that rapidly oscillating currents produce less heating effect than slowly oscillating ones. Moreover, the poles are intensely hot in the arc and comparatively cool in the spark.

But it is apparent that the effect of self-induction is clearly a double action, a repressive effect upon the lines of Groups C and B, and an enhancing effect upon those of Group A. Its whole effect cannot be explained by saying merely that there is a gradual fall in temperature in passing from the spark to the arc; for the spark is a complicated mechanism, and its temperature varies from point to point, and is also a rapidly varying function of the time.

The following table gives a list of the lines belonging to the three groups in the region from λ 2100 to λ 5379 Å. U. No attempt was made to measure them accurately, no more so than was necessary simply to indicate them. Most of the lines occur in Eder and Valenta's table of the cadmium spark spectrum, and these observers have a few lines toward the red end which I do not find, owing possibly to the fact that in this region they photographed the spectrum of the spark in an atmosphere of hydrogen. Some lines have been omitted, a few of which do not fit

in well with any of these groups, while the others are so faint that it was impossible to tell much about them. A list of them is given below.

The following abbreviations are used in the tables:

h —hazy.	½ —barely visible.
vh—very hazy.	*hR*—hazy on red side.
s —sharp.	*hV*—hazy on violet side.
b —broad.	*bR*—broadened toward the red.
r —reversed.	*bV*—broadened toward the violet.
10—very strong.	*2b* —two Ångström units broad.
1 —very weak.	

Lines marked with an asterisk * are given by Eder and Valenta. Pairs of lines marked]* are given by Eder and Valenta as single lines.

GROUP C.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
2	2111.7 *	5	3017.4 *	1	3153.4]*
Fairly *s* 3	2224.5 *	3	25.4 *	2	54.2]
vh 1	2350.4 *	1	27.3	5	57.3 *
2	2426.5 *	1	30.4	3	60.9]*
2	2499.9 *	3	35.9 *	6	61.9]
2	2618.9 *	2	44.2	4	73.6]*
s 2	2668.2 *	6	49 0 *	4	74.5]
Fairly *s* 3	2706.9 *	6	53.3 *	3	76.9 *
2	26.9 *	6	59.5 *	3	78.6 *
s 2	67.0 *	7	65.2 *	2	83.0 *
s 3	2805.5 *	4	69.0]*	6	85.6 *
1	2808.8	3	69.4]	2	95.9]*
5	2910.9 *	2	74.0	2	96.5]
2	26.9 *	4	77.3 *	3	97.9 *
5	48.4 *	7	85.2 *	2	3201.8 *
3	52.1 *	3	88.6]*	5	10.2 *
1	53.2	3	89.3]	2	12.7 *
1	54.6	1	91.0	2	13.8 *
2	64.5 *	3	92.5 *	1	15.5 *
1	65.2	5	95.7]*	5	17.8 *
1	70.1	4	96.1]	3	21.6 *
4	71.4 *	4	3113.2 *	2	24.3
4	87.4 *	5	19.1 *	3	36.7 *
4	96.2]*	5	22.0 *	4	64.5 *
3	96.6]	5	24.7 *	3	77.0 *
1	3003.2	1	28.0	4	83.9 *
2	04.0 *	6	29.5 *	3	86.0 *
3	09.0 *	2	41.7 *	2	3389.8
1	11.3]*	1	45.1	2	3423.5
1	11.8]	2	47.0	2	3486.0
3	14.4 *	1	49.0	1	3695.4

GROUP C.—*Continued.*

SUB-GROUP.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
2b, hR 3	3809. *	5	3977.8 *	2	4131.0 *
3	27.	0.8*b* 2	84.8 *	3	39. *
4	37.9 *	1*b* 4	88.3 *	3	42.0 *
3	40.6 *	1*b* 3	91.8 *	1*b* 4	58.1 *
0.8*b* 3	52.4 *	1	4009. *	2	63.8 *
1.2*b* 3	65.4 *	1*b* 2	18.5 *	1	71.6 *
1	89.9 *	2*b* 4	29.2 *	1*b* 2	92.0 *
1*b* 2	99.4 *	1*b* 1	49.4 *	0.7*b* 3	4216.9 *
1*b* 2	3935.7 *	1	54. *	1*b* 3	45.7 *
1.3*b* 6	40.5 *	0.9*b* 5	94.9 *	3	71.2 *
2	50.9 *	1*b* 4	4114.6 *	3	72.9 *
1*b* 6	59.0 *	0.7*b* 2	16.8 *	1*b* 1	94.3 *
5	76.8 *	1*b* 3	27.1 *		

GROUP B.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
Trifle hazy 2	2168.8 *	4	2418.8 *	9	3250.5 *
6	2194.7 *	5	69.9 *	3*b* 4	3497.5 *
2	2248.9 *	3	87.9 *	7	3535.7 *
b 9	2312.9 *	1	95.5 *	7	4415.9 *
7	1.2 *	*b* 4	2552.2 *	2*b* 10	5338.6 *
2	75.0 *	*vb* 4	2573.1 *	2*b* 10	5379.3 *
3	77.0 *	10	2748.6 *		

GROUP A.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
r 5	2144.5 *	*bR* 6	2677.7 *	9	3261.2 *
5	2239.9 *	3	2712.6	10	3403.7 *
1	62.4	*bR* 4	34.0 *	10	66.3 *
r 8	65.1 *	*bR* 5	64.0 *	9	67.8 *
4	67.5 *	*bR* 4	75.1 *	3	3500.1
br 7	88.1 *	7	2837.0 *	10	3610.7 *
5	2306.7 *	*bV* 1	62.4 *	8	13.0 *
6	2329.4 *	*bR* 5	68.4 *	4	14.6 *
½	2525.6	7	80.8] *	*s* 2	49.7
vk 1	44.9 *	4	81.3]	*hR* 3	3729.2
½	80.3	*bV* 3	2961.7 *	*hR* 4	4307.0
½	92.1 *	8	80.7] *	1	4413.2 *
h ½	2602.0 *	5	81.5]	*bR* 4	4662.7 *
2	29.1 *	½	3005.5	*hR* 10	4678.4 *
1	32.3	*hR* 6	81.0 *	*hR* 10	4800.1 *
4	39.6 *	*hR* 8	3133.3 *	*hR* 10	5085 1 *
h 2	60.4 *	*hR* 8	3252.7 *	*hR* 2	5154.9
h 1	70.7 *				

LINES OMITTED.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave length
1	2004.2	*vh* 1	2411.2 *	½	3156.0
1	2055.5	½	2591.1	1	63.2
½	2148.3	½	93.0	*h* ½	87.5
½	51.6	½	96.0	½	90.5
½	55.5	½	2599.3	½	3219.5
1	88.0 *	½	2780.1 *	½	42.9
½	2345.8	*h* ½	2967.5	½	43.9
½	33.3 *	*h* ½	2968.5	*h* 5	3385.3
½	43.0	½	3032.8	*h* 1	4006.0 *
vh 1	55.2 *	½	41.		

II.

The second part of the investigation is a study of some of the properties of the spark and its spectrum by means of photographs taken with a revolving mirror, and an attempt to trace the connection between lines of different groups and also certain characteristic lines in the spectra of magnesium and zinc, and certain phenomena in the spark itself.

The appearance of the spark when viewed in a rotating mirror turning with sufficient velocity to separate out the oscillations of the condenser is well known. Feddersen studied its appearance in 1862,[1] and Schuster[2] has also photographed it by using, instead of a revolving mirror, a rapidly revolving disk to which was attached a sensitive film upon which the image was focused. Its appearance is shown in Plate III, Fig. 1, which was taken by placing a narrow vertical slit in front of and very close to the spark, and allowing the light to fall upon a rotating mirror with vertical axis and thence through the lens of a camera. Its appearance presents three general features.

1. A brilliant white straight line due to the first discharge, which is sometimes followed by one or two similar weaker straight lines at intervals of half the complete period of the condenser.

2. Curved lines of light which shoot out from the poles toward the center of the spark gap with a velocity constantly diminishing

[1] *Pogg. Ann.*, **116**, 1862. [2] *Phil. Trans.*, **193**, p. 209.

as they move away from the poles. It will be noticed that as the light advances from one pole, the light moving away from the opposite pole is either very weak or absent altogether. In a cadmium spark these lines of light are greenish-yellow and in magnesium they are purple.

3. A rather faint light, generally of a different color from the curved lines of light, which fills up the spark gap and persists for a certain length of time, especially in the center of the spark gap, after the oscillations die out.

If the slit is very narrow, this light is not apt to come out on the photograph, owing to under-exposure, but by widening the slit or removing it altogether it is easy to get it, at the expense, however, of blurring the oscillations.

Schuster, by photographing the spectrum on the rotating disk, has shown that it is the first brilliant discharge to which the air-lines in the spark spectrum are due.

APPARATUS.

In order to get a connection between the different metallic lines and the phenomena in the spark, I arranged an apparatus, a section of which by a horizontal plane is shown in the diagram.

A is the spark, which is vertical. *S* is a vertical slit very close to it. At a considerable distance away, 231 centimeters, was placed a 60° prism, *P*, of flint glass, with its edge vertical. It was set at an angle of minimum deviation for a wave-length about 4500. At *M* was a rotating mirror with its axis horizontal. The mirror was driven by an air blast and its period measured by a speed wheel attached to the axis of the mirror by a worm gearing. The highest speed obtainable was 65 revolutions per second. The light reflected from the mirror passed through a lens and was focused on the ground glass of a camera, *C*. In this way a horizontal spectrum was obtained whose height, *i. e.*, the length of whose lines, was very small (0.7 mm).

PLATE III.

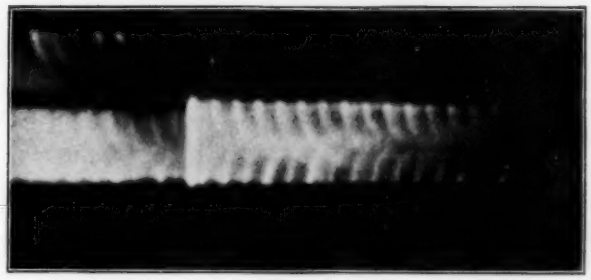

FIG. 1.

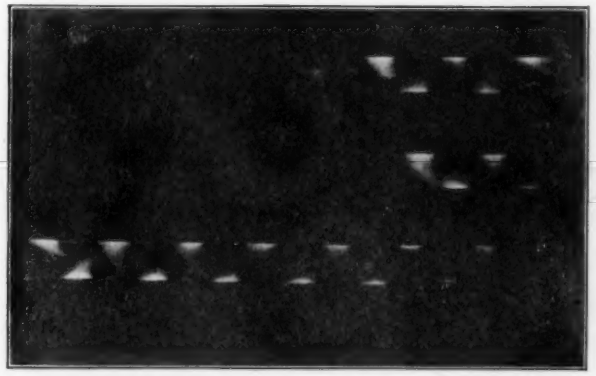

FIG. 2.

By the rotation of the mirror the lines of the spectrum were pulled out in the direction of their length, by an amount depending upon their duration and upon the speed of the mirror. The time of exposure was found by trial, and was taken so that four or five flashes of the spectrum were thrown upon the plate, as a rule in different places. Photographs were taken using pairs of cadmium, zinc, and magnesium electrodes, and also by using one electrode of cadmium and one of magnesium, etc. By measuring the length d, of any line on the plate as pulled out by the mirror, and knowing the period of the mirror, T, the optical distance from the slit to the mirror, r, the small angle, 2θ, between the incident and reflected light at the surface of the mirror when the normal to its surface lay in a horizontal plane, and the magnification, f, of the image of the slit in the camera, it was easy to calculate the duration, t, of the different lines by the formula,

$$t = \frac{Td}{4\pi f r \cos\theta} .$$

With this apparatus,

$$r = 230.9 \text{ cm}$$
$$f = \tfrac{6}{55}$$
$$\frac{1}{\cos\theta} = 1.043 .$$

The first striking characteristic of the lines was that the principal arc lines (Group A) were at least twice as persistent as the strongest spark lines (Group B).

The following table gives an example of the duration of some of the principal lines of magnesium, zinc, and cadmium.

	Line		Duration
Magnesium	4481	strong spark line	24×10^{-6} seconds
	3838, 3832, 3830	strong arc triplet	45×10^{-6}
Zinc	4925	strong spark lines	14×10^{-6}
	4912		14×10^{-6}
	4811	strong arc lines	24×10^{-6}
	4722		24×10^{-6}

	Line		Duration
Cadmium	4800, 4678	strong arc lines	36×10^{-6}
	4416	strong in spark, extremely weak in arc	18×10^{-6}

It was determined by eye observations that the duration of the principle arc lines was even greater than is indicated in the above table, the extreme end of the lines not appearing on the photograph owing to under-exposure.

The period of the condenser was 1.3×10^{-6} seconds. The duration of the continuous spectrum, which appeared quite strong by using such a small dispersion, was exceedingly short; *i. e.*, less than the period of the condenser. The air lines also, as might have been expected from Schuster's results, persisted for a length of time equal to one or two periods only.

Now, owing to the fact that the height of the spectrum is not small enough, and also that the mirror could not be run faster than 65 revolutions per second, it was impossible to show oscillations in the lines by this arrangement, but by increasing the period of the condenser to 5×10^{-6}, by a small self-induction, and by using poles of unlike metals, say zinc and cadmium, the oscillations were brought out very clearly.

A second characteristic of the lines was that the spark lines (Group B), appeared sharply beaded clear out to their ends, as a result of the oscillations, while the arc lines (Group A) showed only indistinct traces of beading, which did not extend all the way out to the ends of the lines. In other words, the spark lines are due entirely to the oscillations, and the arc lines are due partly to the oscillations and partly to something else which retains its luminosity after the oscillations cease. On some of the photographs the magnesium arc triplet at λ 3830 began a trifle later than the spark line λ 4481. This fact will be referred to later.

This seemed to point to a connection between the spark lines and the curved streams of light seen in the spark itself when viewed in a revolving mirror. To show this clearly, the mirror

PLATE IV.

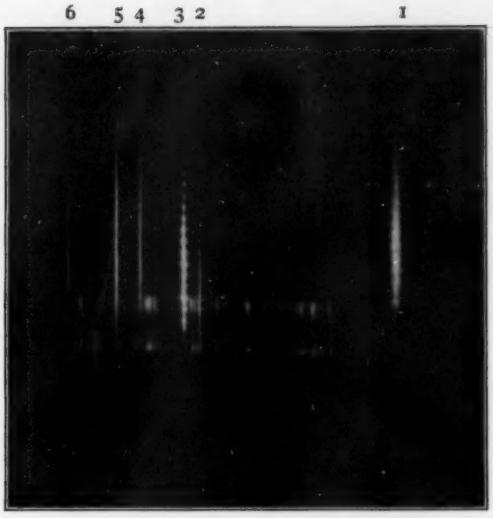

FIG. 3.

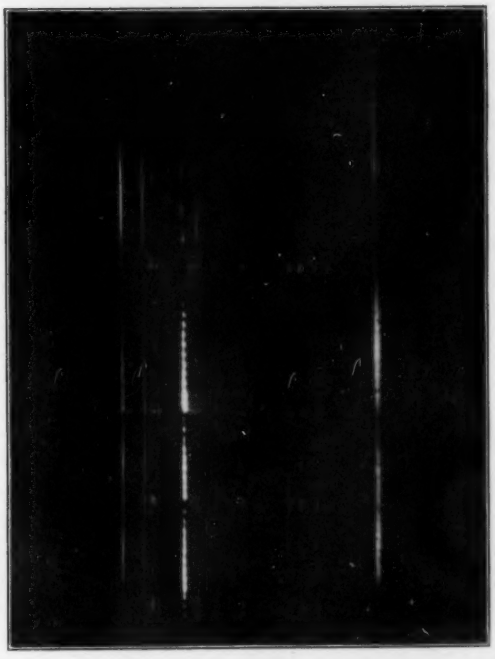

FIG. 4.

was turned over in order that its axis might be vertical, and the front half of the camera lens was removed so as to get a higher spectrum, *i. e.*, one whose lines should be longer, and also to spread out the oscillations. The period of the condenser was again reduced to 1.3×10^{-6}, by removing the self-induction, and magnesium poles were used on account of the extreme brilliancy of the spark line λ 4481. In the photograph, this line appeared broken up into a beautiful series of curved lines similar to the curved streamers in the spark itself.

In order to see if there were an exact similarity between the streamers in the spark and those into which this magnesium line was broken, the apparatus was arranged as follows: An image of the spark was focused on a vertical slit by means of a lens. The light then passed through a collimating lens, was transmitted through the prism in a parallel beam and fell upon the revolving mirror (with vertical axis), from which it was reflected into the camera, and the spectrum brought to a focus on the ground glass. The prism was mounted upon a sliding block, and a plane vertical silvered mirror was placed near its refracting edge upon the same block, so that, by sliding the block, a part only of the light passed through the prism, while the rest struck the silvered mirror from which it was reflected to the revolving mirror and thence into the camera, forming an undispersed image of the slit alongside of the spectral image. By tilting the silvered mirror very slightly out of the vertical, the undispersed image was thrown on the plate slightly above and one or two centimeters to one side of the spectral image. By this means it was possible to get a plain and a dispersed image of the *same* spark which did not overlap when the mirror was spinning. But no difference was found on the photograph, between the appearance of the streamers in the plain spark and those in the line λ 4481, every slight irregularity in the one appearing also in the other.

It was not found possible, on account of lack of light, to photograph the arc lines by any of these methods with the axis of the mirror vertical, without cutting down the speed of the

mirror so much as to run the oscillations together. But even under these conditions the arc lines showed certain interesting features. The light from the magnesium triplet λ 3830 advanced from the poles toward the center of the spark gap with substantially the same velocity as that from the line λ 4481, but with feeble intensity, and burst out in the center of the gap with increased brilliancy an instant later, where it remained until some time after the spark line λ 4481 had ceased. This agrees with the fact, mentioned on page 126, that this arc triplet began a trifle later than the spark line λ 4481, its feeble intensity at the start not appearing on the photograph referred to on that page.

But in order to establish the exact connection between the principal arc lines and the curved streamers in the plain spark, it was necessary to resort to eye observations. The following apparatus was set up: The image of the spark was thrown on the slit of a Steinheil spectroscope containing two flint-glass prisms, and the eyepiece of the observing telescope was removed so that the spectrum was brought to a focus in the focal plane of the telescopic objective. A vertical slit was placed at the spectrum so as to transmit the light of any particular line desired. The light then fell upon the rotating mirror (with vertical axis) about 16 inches away, and was reflected into the camera and brought to a second focus on the ground glass. By spreading out the oscillations with a small self induction the following phenomena could be clearly seen by careful observation.

For cadmium.—The strong spark lines λ 5339 and λ 5379 appeared as a beautiful series of curved streamers sharply defined and separated clearly by dark spaces. The last two or three streamers did not proceed very far from the electrodes and the center of the spark gap at this instant was dark.

The line λ 4416 (strong in spark and very weak in arc) also showed oscillations, but its total duration was only about half that of λ 5339 and λ 5379.

The strong arc line λ 5086 also appeared as a series of curved streamers which were *not* clearly separated by dark spaces, and the center of the spark gap remained filled with light after the

streamers ceased. Its total duration exceeded that of λ 5339 and λ 5379.

For magnesium.— The strong spark line λ 4481 appeared (as had been previously proved by the photographs) as a series of clearly defined curved streamers.

The strong arc triplet at λλ 5184, 5173, 5168 (*b* lines) also appeared in the form of curved streamers, but there was, besides, a luminosity which persisted long after the streamers ceased, so that the total duration of these lines was about four times that of λ 4481. The luminosity lasted longest in the center of the spark gap.

The oscillatory character of these lines was also verified visually by Mr. L. A. Parsons, Fellow in this University.

RESULTS.

It follows from these observations and the photographs, that the strong spark lines λ 5339 and λ 5379 of cadmium (Group B), and λ 4481 of magnesium are due entirely to the curved streamers in the spark; also that the spectrum of the last few streamers in the cadmium spark does not contain so many lines as that of the first few, *i. e.*, the line λ 4416.

The principal arc lines λλ 5086, 4800, 4678 of cadmium (Group A), and the triplets at λ 5170 and λ 3830 in magnesium are also due partly to the streamers, but a large part of their luminosity is due to something else which appears in the center of the spark gap a trifle later than the first discharge, spreads throughout the gap and retains its luminosity after the streamers cease, retaining it longest in the center of the gap.

This latter luminosity is without doubt due to the metallic vapors.

The fact that the arc lines are due in part to something else besides the streamers was rather strikingly shown by inserting a considerable self induction (0.0093 henries) in the spark circuit. As stated above, the principal spark lines show a tendency to shorten up close to the poles while the arc lines go clear across the spark gap. Now when the spark itself is viewed

in a rotating mirror under these conditions, the streamers do not advance so far from the poles as with the ordinary spark, while the center of the spark gap is filled with a pale light whose color and intensity are quite different from those of the streamers.

Fig. 2 is a photograph of the spark under these conditions using cadmium electrodes. The streamers come out on the photograph, but the faint light in the center of the spark, while clearly visible to the eye, was too faint to appear on the negative. The period of the condenser was in this case about fifty-eight times as great as with the ordinary spark. It will be noticed that the initial straight discharge has disappeared. This was to be expected, since Schuster showed that a self induction cuts out the air lines, and that the air lines are due to the initial discharge.

The streamers emanate from the kathode.—It is known already that the streamers proceed from a pole of the same nature. Feddersen's results were somewhat irregular so that he was unable to lay down any general law as to which pole emitted the stronger luminosity. In order to determine whether this were kathode or anode, I charged the condenser by an electric machine and carefully tested the electrification of its terminals with a gold leaf electroscope just before the spark passed. Two or three photographs of the spark were taken under these conditions using magnesium electrodes. Knowing the electrification of the poles at the first discharge, it was comparatively easy to tell from the photographs whether the streamers proceeded from a positively or a negatively electrified electrode. In each photograph they proceeded from the negatively charged pole.

The streamers do not carry the current.—It is easy to see by an inspection of the plates that the streamers shoot out from the poles with gradually diminishing velocity, and that before they get more than half way across the spark gap, the entire charge has passed across and the return oscillation is beginning.

Spark with very hot poles.—It must be remembered that the results of this investigation hold only for comparatively cool

electrodes. With magnesium poles, by inserting a small self induction and increasing the primary current from 12 to 25 ampères, small white-hot globules formed on the electrodes. When this occurred, the noise of the spark greatly diminished, the spectrum showed marked changes, and the appearance of the spark in the rotating mirror was quite different. The strong spark line λ4481 shrunk down close to the electrodes, while the arc triplet at λ5170 did not. The spark when viewed in the mirror showed a luminosity advancing from the poles to the center of the spark with far less velocity than that of the customary streamers. As far as could be made out, there were also feeble streamers present which advanced only a short distance out from the poles. Every now and then the little globules would fly off the poles, the loud noise would return, and the ordinary streamers would instantly reappear in the spark. The spark line λ4481 then stretched clear across from pole to pole.

The result of this investigation may be expressed briefly by saying that the chief cause of the complexity of the spark spectrum is the presence of the luminous streamers in the spark.

As to their nature, they may be luminous pulses, something like those that occur in a Geissler tube discharge. Or they may be metallic vapors, the peculiar vibration of whose atoms is set up by the act of tearing them off the electrodes; as they moved off from the electrodes, the abnormal vibrations would die out, while the more fundamental vibrations, principal arc lines, would persist—would indeed be augmented by the passage of the to-and-fro currents through the vapors.

In conclusion, the author wishes to express his thanks to Professor Ames for his kindness and for the many fruitful suggestions made during the course of this work.

ADDENDA.

EFFECT OF A STRONG MAGNETIC FIELD.

Some experiments were also made upon the effect produced by placing the spark in a strong magnetic field. The spark terminals were placed between the poles of a large electro-magnet,

and a mirror was arranged so that light from the spark which was propagated along the lines of magnetic force was reflected to a lens, thence to a slit upon which the image of the spark was focused. The light then passed along to a collimating lens, to the revolving mirror with vertical axis, from which it was reflected through the lens of a camera and brought to a focus on the ground glass, the lens being adjusted for parallel rays. By a variation in the above arrangement, the light from the collimating lens could be made to pass through a couple of prisms, then through another lens, then, at a distance away sixteen inches greater than the focal length of the last lens, upon the revolving mirror, and into the camera. By the latter arrangement, the behavior of the separate lines of the spectrum could be studied when subjected to a strong magnetic force.

Perhaps the most interesting feature of the change produced is that the spark lines (Group B) and the arc lines (Group A) behaved quite differently. With no magnetic field they were both long lines, *i. e.*, extended clear across the spark gap. With the magnetic field, the magnesium spark line λ 4481 extended outward from each pole only about a quarter of the way across the gap, leaving the center free from light of this wave-length, while the arc triplet at λ 5200 extended clear across as it did without the field. When examined with the mirror revolving, the line λ 4481 was broken up into a series of short streamers separated by intervals of darkness, while the arc triplet λ 5200 was in the form of a luminosity which advanced slowly (with a velocity not greater than 0.5×10^4 cm per second) toward the center of the spark gap, where it remained luminous for about 160×10^{-6} seconds, the luminosity as it moved from the poles to the center of the gap being crossed by a series of streamers. The noise of the spark was increased by the magnetic field.

In these experiments the period of the condenser was 5.5×10^{-6} seconds, the strength of the field about 10000. The velocity and duration of the luminosity were measured by a series of careful visual observations.

PLATE V.

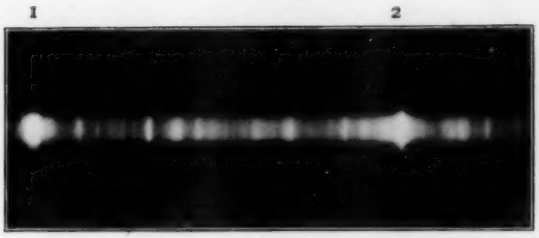

FIG. 5.

FIG. 6.

FIG. 7.

Velocity of the streamers.—As there are two distinct phenomena in the spark that might indicate the velocity with which the metallic vapors advance from the poles toward the center of the spark gap, a few plates were measured up in order to distinguish between them,

1. By measuring the slope of the streamers in the magnesium line λ 4481 on a photograph of the spectrum taken with the revolving mirror, it is possible to determine the velocity with which the streamers shoot out from the poles. The value of the velocity obtained in this way was not far from 25×10^4 cms. per second. About a millimeter out from the pole the velocity falls to 16 or 18×10^4.

2. Now the appearance of the line λ 4481 in the rotating mirror often shows a peculiarity which would seem to indicate a second velocity. The first streamer shoots out only a little way, the next one a little farther, and the third still farther, so that the locus of the extremities of successive streamers, when viewed in the rotating mirror, forms an inclined line which is sometimes fairly straight but which is sometimes irregular, owing to the fact that the distances to which successive streamers advance do not increase strictly in arithmetical progression. If the slope of this line be regarded as indicating a velocity it gives a value less than one fifth of the maximum velocity of the streamers, *i. e.*, about 4×10^4. Now, this is not far from some of the values found by Schuster[1] and Hemsalech in their work on the spark, and interpreted by these observers as the velocity of the metallic vapors. But the appearance of my negatives points to the conclusion that the slope of this line does not indicate a velocity, but is in most cases a sort of envelope of successive streamers, and that this is probably what Schuster and Hemsalech have measured in many cases. As pointed out by Schuster, this apparent velocity is not far from that of a sound wave, and if we assume that the violent sound emitted by a spark is produced by the expansion of a column of air raised to high temperature and therefore to high

[1] *Phil. Trans.*, 193, pp. 189–213.

pressure by the first discharge (for if the temperature of a gas is raised, the density remaining constant, the pressure is raised also), it is rational to suppose that the distances to which successive streamers advance would increase as the pressure of the air which opposes their motion becomes less and less.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., June 1901.

DESCRIPTION OF THE PHOTOGRAPHS.

Plate III, Fig. 1. Spark, cadmium electrodes. Period of the condenser, 5×10^{-6}. Mirror is turning in such a direction that light appears at the left of the image first. In this photograph the exposure was so long that another spark happens to have struck the plate just to the left of the principal one. A fragment of a third spark appears above the latter, which was gotten by raising the lens of the camera. There is also a luminosity which persists after the oscillations die out, which fails to appear on the photograph, owing to under-exposure.

Plate III, Fig. 2. Spark, cadmium electrodes. Period of condenser, 75×10^{-6}. Three images appear upon the plate. In the upper two, the plate was not long enough to catch more than two or three oscillations.

Plate IV, Fig. 3. Spark spectrum photographed with rotating mirror whose axis of rotation is horizontal. The lines are thus pulled out vertically upwards. The upper pole is magnesium and the lower, cadmium. One notices the distinct beading in the magnesium spark line λ 4481, (3), and the indistinct beading in the arc triplet λ 3830, (1). The greater duration of the latter is also apparent, though not very clearly so on this particular photograph. The oscillations in the cadmium spark line λ 4415, Fig. 2, also appear, but those in the arc lines λλ 4678, (4), 4800, (5), and 5086, (6), do not. This is because the mirror is turning in the most favorable direction for bringing out the oscillations in the magnesium, and not in the cadmium lines. The magnesium line λ 4481, (3), being due to puffs that shoot downwards from the poles, the action of the mirror is to diminish or to arrest their apparent motion, thus separating them into a series of distinct beads. With the cadmium lines the puffs shoot upwards, and the mirror prolongs each into a line of light thus rendering the oscillatory effect less clearly visible. I have another negative taken with the cadmium pole on top in which the oscillations of the cadmium lines are clearly shown, to the detriment, however, of those of the magnesium lines. It will be noticed that two separate sparks appear on this negative, shown by the two sets of air lines. The lower part of the magnesium line λ 4481 belongs to the lower spectrum. With the mirror at rest the length of all the lines would be about the same as that of the upper set of air lines.

PLATE VI.

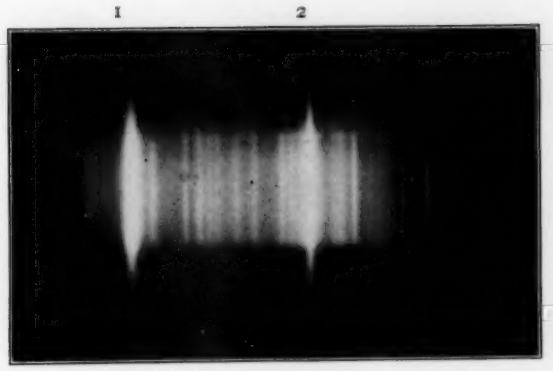

FIG. 8.

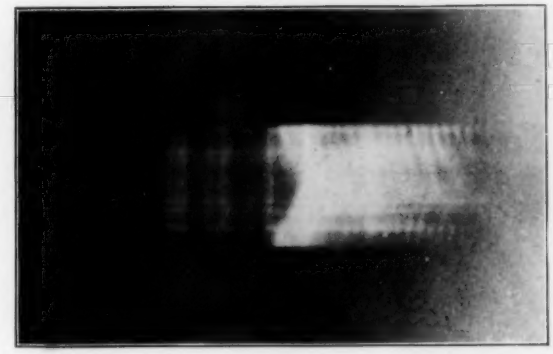

FIG. 9.

Plate IV, Fig. 4. Same as Fig. 3 except that four flashes of the spark appear. The air lines also are somewhat weak on the enlarged print. It will be remembered that these impressions are not made by four *consecutive* sparks, as the interval between consecutive sparks was 100 times as great as the entire duration of a single spark. In Figs. 3 and 4 the period of the condenser was 5×10^{-6}.

Plate V, Figs. 5, 6, and 7 show the magnesium spectrum with the axis of the mirror vertical. In Fig. 5 the mirror is at rest, in Fig. 6 it is making 11¼ revolutions per second, and in Fig. 7, 65½ turns per second. In Fig. 6 we notice the tendency of the arc triplet at λ 3830, (1), to appear most brilliant in the center of the spark gap; also its greater persistence compared with the spark line λ 4481, (2). In Fig. 7 the spark line 4481, (2), appears broken up into a regular series of twelve or more streamers. We also see the two *less* steeply inclined lines of light advancing from the poles to the center of the spark gap, where the line λ 4481 starts out. The arc triplet at λ 3830, (1), does not appear, owing to lack of light, while the air lines are scarcely changed by the rotation of the mirror.

Plate VI, Figs. 8 and 9 show also the separation of the same line, λ 4481 magnesium, (2), into a succession of about eighteen curved streamers, the air lines being straight and hazy. The arc triplet at λ 3830, (1), again disappears for lack of light. The horizontal lines of light in Fig. 9 are due to inequalities in the width of the slit. The spark length was the same, seven millimeters, in Figs. 5, 6, 7, and in Figs. 8 and 9, but Figs. 5, 6, and 7 were taken with the objective prism, and Figs. 8 and 9 with a collimating lens which produced a wider spectrum. In Figs. 5, 6, 7, 8, and 9 the period of the condenser was 1.3×10^{-6}.

Minor Contributions and Notes

NOTE ON A NEW FORM OF RADIOMETER.

The radiometer, as described by E. F. Nichols (*Wiedemann's Annalen*, **60**, 401, 1897), was found by the writer to possess a few disadvantages in point of ease of adjustment, to overcome which a different form of case was devised. The difficulties found were as follows: (1) air was very apt to leak into the apparatus; (2) the suspended system frequently became charged with static electricity and thereby took on a short period; (3) it was inconvenient not to be able to turn the suspension about a vertical axis, if from any cause, such as electrification, it became necessary to do so to keep the vanes in the desired direction.

Fig. 1.

The form of case finally adopted was as shown in Fig. 1. The tube *A* was of heavy glass 1.5 cm inside diameter, and near the lower end of it were blown two openings, facing, as usual, in directions at right angles to each other, the outside edges of which were ground flat, so that they could be closed with plates. The two openings were sufficiently far apart so that stray radiation from the beam used to illuminate the moving mirror could not reach the sensitive vanes, and the whole inside of the tube was deeply blackened, a little of the blacking being scratched off in one or two places, where necessary, to allow the system to be seen and adjusted in position. The lower opening, *C*, was closed with a small spectacle lens of one meter focal length, sealed in with wax, and the motions of the mirror of the system were observed by means of a beam focused by this lens. The opening *B* was closed as shown in Fig. 2, which is a vertical section through *B*. *P* was a brass plate cemented to the glass, with a hole in the middle of it of suitable size to admit the beam of radiation to be

studied and to be covered by a small plate of polished rock salt *S*, which was cemented to it. *T* was a small piece of tin, fastened to the glass inside, supporting a second plate of rock salt *R*, which stood opposite the sensitive vanes at the distance required for great sensitiveness. This distance could be varied at will by altering the level of the apparatus. A couple of small strips of tin foil, pointed and cut at the ends passed from *P* along *T* and projected into the tube and over part of *R;* these served to dissipate the static electric charges which arose when the air was drawn out of the tube or when the wax used as a cement was touched.

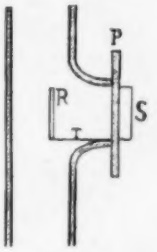

FIG. 2.

The upper end of the tube *A* was ground for a mercury-sealed joint into which fitted another tube *F*, including a mercury-sealed stopcock at *M* and leading to the air pump. A wire *W* was attached to the lower part of the tube *F* and a very fine quartz fiber hung from this inside the tube *A* and supported the radiometer system. The whole radiometer was supported by a sort of Julius suspension. When the radiometer is attached to the pump, this arrangement is slightly disturbed, but only slightly, as there must be one or two rubber joints between the radiometer and the pump, which assist in preventing the passage of mechanical disturbances along the tubes. The joints about the openings *B* and *C* may, however, on account of their smallness and simplicity, be so perfectly sealed as to admit of the pump being completely detached for a month at a time. A leak at the upper end of the tube is impossible if the mercury seals are in order. The radiometer may then be left free and the Julius suspension may be used with complete success.

In this condition the radiometer is nearly free from mechanical disturbances, the system may be turned at will without changing the pressure within the tube, and thus the zero point may be adjusted; the electric charges are dissipated within an hour or two after exhaustion, and the apparatus is practically air-tight. Its high sensitiveness and, in this form particularly, its cheapness and ease of adjustment, make it an extremely valuable instrument for radiation experiments.

F. A. SAUNDERS.

SYRACUSE, N. Y.

SOME RECENT RESULTS SECURED WITH THE MILLS SPECTROGRAPH.[1]

The results contained in this *Bulletin* are a few of those recently established by the Mills spectrograph, used in connection with the 36-inch refracting telescope. The majority of the photographs upon which the results depend were made by Assistant Astronomer W. H. Wright, and the remainder by Dr. Reese and myself.

W. W. CAMPBELL.

June 20, 1901.

I. A LIST OF SIX STARS WHOSE VELOCITIES IN THE LINE OF SIGHT ARE VARIABLE.

The following six spectroscopic binaries, discovered with the Mills spectrograph, are additional to the twenty-five already announced.

π CEPHEI ($\alpha = 23^h\ 05^m$; $\delta = +74^\circ\ 51'$)

The binary character of this star was suspected in August 1899, from the fact that the approximate measures and reductions of the first and third plates showed a range of four kilometers in the observed velocities. Later plates confirmed the fact of the variation. The observations to date are as follows:

Date			Velocity
1899	August	8	− 33 km
	August	23	− 36
	August	29	− 37
1900	October	7	− 5
	December	24	− 23

o_1 31 CYGNI ($\alpha = 20^h\ 10^m$; $\delta = +46^\circ\ 26'$)

The variability was detected in July 1900, from the third plate.

Date			Velocity
1899	June	20	− 12 km
	July	2	− 11
1900	July	30	− 3
	August	12	− 3
	October	7	± 0
1901	June	5	+ 3

This star was discovered to have a composite spectrum by Harvard College Observatory. [*Annals H. C. O.*, **28**, 93.]

ξ PISCIUM ($\alpha = 1^h\ 48^m$; $\delta = +2^\circ\ 42'$)

[1] *Lick Observatory, University of California, Bulletin* No. 4.

The variable velocity of this star was discovered in September 1900, from measures of the third plate.

	Date	Velocity
1899	September 5	+ 25 km
	September 19	+ 27
1900	September 17	+ 33
	December 26	+ 35

τ PERSEI ($\alpha = 2^h\ 47^m$; $\delta = 52^\circ\ 22'$)

The variable velocity of τ *Persei* was discovered from the fourth plate of its spectrum, in October 1900.

	Date	Velocity
1898	October 26	+ 10 km
	November 14	+ 8
	November 28	+ 8
1900	October 15	— 2
	October 31	— 3
	December 17	— 4

It was discovered at Harvard College Observatory that this star has a composite spectrum. [*Annals H. C. O.*, **28**, 93.]

ξ_1 CETI ($\alpha = 2^h\ 08^m$; $\delta = 8^\circ\ 23'$)

The variable velocity of this star was discovered from the fourth plate, in October 1900.

	Date	Velocity
1897	October 27	— 9 km
1898	October 10	— 7
	October 17	— 8
1900	October 29	+ 4
	December 4	+ 1

ϵ HYDRAE ($\alpha = 8^h\ 42^m$; $\delta = +\ 6^\circ\ 48'$)

The variable velocity of this star was detected from the third plate, in December 1900.

	Date	Velocity
1899	November 27	+ 43 km
	December 26	+ 43
1900	December 3	+ 35
	December 24	+ 40
1901	April 23	+ 32

II. RADIAL VELOCITIES IN THE SYSTEM OF δ *EQUULEI*.

This is one of the most interesting double stars known, discovered by Otto Struve in 1852. Its period of revolution was supposed to be

11.4 years. It was placed on the observing program for the Mills spectrograph, and its radial velocity was observed, as follows:

Date		Velocity
1900	June 25	− 14 km
	July 9	− 13

No peculiarities such as doubling of the lines due to the two components, were apparent in the spectrum. This result was anticipated, as the two components were known to be moving approximately parallel to the line of nodes of their orbit; that is, at right angles to the line of sight.

In September 1900, Assistant Astronomer Aitken's observations of this star showed that the long-accepted orbits were unsatisfactory [*Publ. A. S. P.*, 12, 255–257]; and Astronomer Hussey's investigations rendered it probable that the period is only 5.7 years [*Publ. A. S. P.* 12, 215–223].

Special efforts have been made to secure spectrographic observations of δ *Equulei* this spring with a view to solving the difficult question of the star's period. A few successful negatives have been obtained within the past two months. The spectra of the two components are clearly shown with displacements corresponding to a relative velocity at present of about 35 kilometers per second. If the distance between the corresponding lines decreases and vanishes in the next few months, we shall have conclusive proof that the period of the star is in the vicinity of 5.7 years; otherwise the longer period should have the preference.

III. RADIAL VELOCITIES IN THE SYSTEM OF *POLARIS*.

It was discovered in August 1899, from observations made with the Mills spectrograph, that α *Ursae Minoris* (*Polaris*) is a triple star. A few observations secured that month showed at once that the bright component was moving around the center of mass of itself and an invisible companion in a period of about 3 days 23 hours. Six observations secured in 1896, extending over three months, were best satisfied on the assumption that the period is $3^d\ 23^h\ 15^m$. A comparison of the 1896 and 1899 observations furnished a period of $3^d\ 23^h\ 14^m.3$.

The velocity of the center of mass of this system varied from − 18.0 km per second in 1896 to − 11.8 km in 1899, thereby affording proof that this system was revolving around the center of mass of itself and a third body in a relatively long period of time.

Further observations have been secured at intervals since August 1899, for the purpose of detecting the first evidence of change in velocity of the center of mass of the short period system. Changes suspected in the latter half of 1900 have now become certain; the velocity of the center of mass of the binary system has varied from — 11.8 km in 1899 to about — 13.5 km at the present time.

The period of the binary system, $3^d\ 23^h\ 14^m.3$, deduced in 1899 seems to satisfy recent observations perfectly.

IV. THE RADIAL VELOCITY OF α *PERSEI*.

Mr. H. F. Newall, from observations made at Cambridge, England, has announced [*The Observatory*, December 1900] that the velocity of α *Persei* is variable. His results lie between — 4 and + 8 km per second and were secured in the years 1899 and 1900. The following table contains all the Mills spectrograph observations of this star, with the time-intervals between successive dates:

	Date	Velocity	Interval
1896	November 11	—2.0 km	
			1 day
	November 12	—1.8	
			68
1897	January 19	—3.5	
			539
1898	July 12	—2.1	
			440
1899	September 25	—1.5	
			447
1900	December 16	—2	
			10
	December 26	—2	
			4
	December 30	—2	
			0
	December 30	—3	
			14
1901	January 13	—2	

These ten observations, made in six different years, exhibit a range of only two kilometers. Since this is about the usual range for such stars, due largely to changes in the observer's personal habits in measuring the plates, we may say that these observations afford no evidence of variable velocity.

V. THE RADIAL VELOCITY OF θ *URSAE MAJORIS*

Observations of this star at Pulkowa in the years 1894 and 1896 by Dr. Bélopolsky gave results ranging from + 1 km to + 22 km per second;

and it was announced as a spectroscopic binary with a period of from five to seven days. [*Astr. Nach.*, No. 3549; ASTROPHYSICAL JOURNAL, 11, 383]. Results obtained by the same observer in February and March 1899, ranging from + 7 km to + 19 km, were considered by him to furnish no evidence of variable velocity during those months [*Astr. Nach.*, No. 3603].

The Mills spectrograph observations, as published below, do not indicate variable velocity:

	Date	Velocity
1897	November 16	+ 15 ± km
1899	December 18	+ 16
	December 24	+ 15
	December 27	+ 14
1900	January 30	+ 14
1901	January 27	+ 14

VI. THE VARIABLE VELOCITY OF *δ ORIONIS* IN THE LINE OF SIGHT.

The variable velocity of this star was discovered by M. H. Deslandres from observations made with the great Meudon refractor. This star is not on the program for the Mills spectrograph, as its lines are very broad and unsuitable for accurate measurement. However, Mr. Wright has secured three observations, as below, which confirm M. Deslandres' discovery:

	Date	Velocity
1900	August 12	+ 3 km
	August 21	+ 51
	September 17	— 69

VII. THE VELOCITY OF *GROOMBRIDGE* 1830 IN THE LINE OF SIGHT.

The star No. 1830 in Groombridge's catalogue is of special interest on account of its large proper motion. Its position in the heavens is changing at the rate of 7″.05 per year, a speed sufficient to carry it over one degree in five hundred years. This was the maximum stellar motion known up to the year 1898, at which date an eighth-magnitude star in the southern hemisphere was found to have a proper motion of 8″.7 per annum.

Several determinations of the parallax of *Groombridge* 1830 have been made. The separate results differ widely in value, but they are in substantial agreement in placing the star at a great distance. From a consideration of the merits of the individual determinations, Newcomb has adopted 0″.14 as its most probable parallax. Assuming this

to be its true value, the component of the star's velocity at right angles to the line of sight is 240 kilometers (150 miles) per second. This is by far the largest cross-motion assigned for any of the stars whose parallaxes have been measured.

Inasmuch as the proper motion, both in arc and in linear measure, takes account of the component measure at right angles to the line of sight, it is of unusual interest to have a determination of the component of speed in the line of sight. This determination has been made with the Mills spectrograph, after replacing its three dense prisms by one light prism.

Four spectrum photographs have recently been secured, of which two are very satisfactory, and one is excellent. The results given by the four are in substantial agreement; those given by the best two are —93 and —97 kilometers (58 and 60 miles approach) per second, for the dates 1901 March 18 and April 1, respectively. Their mean value, —95 kilometers, is possibly uncertain to the extent of 5 kilometers.

In view of the great uncertainty existing in the value of the parallax, no interest attaches to the resulting value of the angle for the direction of the star's motion in space.

Groombridge 1830 is of the 6.5 visual magnitude. The photographic magnitude, on the *Draper Catalogue* standard, must be in the vicinity of 7.5. The spectrum is approximately of the solar type, though it may incline strongly toward the characteristics of *Procyon* or *α Persei*.

The best photograph was secured with an exposure of two hours, in average seeing, using slit-width 0.032 mm. As the collimator is 28.5 inches long, and the camera 16 inches, the equivalent of slit-width, so far as purity is concerned, for a collimator equal in length to the camera, would be 0.019 mm. The measurable lines on this plate are between λλ 4000—4415. The region λ 4415—*Hβ* is overexposed. The spectrum is about 0.25 mm in width. The light flint prism used gives approximately two ninths as much dispersion as the three Mills prisms.

The greatest interest of the observations lies in the fact that fairly accurate determinations of stellar velocities are shown to be possible down to the eighth or ninth photographic magnitude, provided the spectra contain well defined lines. The field available for investigation by these instruments and methods is shown to be practically endless; and no doubt this field is fruitful beyond our most hopeful

expectations. As soon as half-a-dozen of the great telescopes now engaging in this work have been made to produce accurate results, it will be highly desirable that a scheme of coöperation on a large scale be arranged and carried out by the interested observatories.

OBJECTS HAVING PECULIAR SPECTRA.[1]

A LIST of stars having peculiar spectra, and found by Mrs. Fleming from an examination of the Draper Memorial photographs, is given in the annexed table. The designation of the star, its approximate right ascension and declination for 1900, its catalogue magnitude, and a brief description of its photographic spectrum, are given in the successive columns of the table. The remarks following the table furnish additional details of the spectrum and, in some cases, a more accurate determination of the position as derived from a photograph, when the object is not a catalogue star.

TABLE I.

PECULIAR SPECTRA.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m	° ′		
.....	0 56.0	−72 42	.....	Type V. Gal. long. 268° 10′, lat. − 45° 15′
.....	1 6.2	−73 44	.....	Gaseous nebula. Gal. long. 267° 29′, lat.−44° 9′
.....	4 49.9	−69 21	.....	Gaseous nebula. Gal. long. 247° 21′, lat.−35° 41′
.....	4 52.6	−69 33	.....	Gaseous neubla. Gal. long. 247° 31′, lat.−35° 24′
.....	4 55.1	−69.21	.....	Gaseous nebula. Gal. long. 247° 13′, lat.−35° 14′
.....	4 55.7	−66 26	.....	Type V. Gal. long. 243° 42′, lat.,−35° 50′
.....	4 56.8	−66 32	.....	Gaseous nebula. Gal. long. 243° 48′, lat.−35° 42′
.....	4 57 3	−66 33	.....	Gaseous nebula? Gal. long. 243° 48′, lat.−35° 39′
.....	4 57.5	−68 35	.....	Gaseous nebula? Gal. long. 246° 15′, lat.−35° 12′
.....	4 57.8	−68 33	.....	Type V. Gal. long. 246° 12′, lat.−35° 11′
.....	5 0.4	−70 20	.....	Type I. $H\beta$ and $H\gamma$ bright.
.....	5 3.0	−66 49	.....	Type V. Gal. long. 244° 0′, lat.−35° 3′
.....	5 10.2	−69 0	.....	Type V. Gal. long. 246° 27′, lat.−34° 0′
.....	5 10.3	−69 1	.....	Type V. Gal. long. 246° 28′, lat.−33° 59′
.....	5 13.8	−67 29	.....	Type V. Gal. long. 244° 35′, lat.−33° 54′
.....	5 14.8	−69 25	.....	Type V. Gal. long. 246° 52′, lat.−33° 31′
.....	5 22.2	−68 3	.....	Gaseous nebula. Gal. long. 245° 8′, lat.−33° 3′
.....	5 22.5	−68 4	.....	Gaseous nebula. Gal. long. 245° 9′, lat.−33° 1′
.....	5 23.9	−71 43	.....	Tpye V. Gal. long. 249° 26′, lat.−32° 25′
.....	5 24.6	−71 26	.....	Type V. Gal. long. 249° 5′, lat.−32° 24′
.....	5 26.4	−67 35	.....	Type V. Gal. long. 244° 32′, lat.−32° 42′
.....	5 27.1	−68 55	.....	Type V. Gal. long. 246° 6′, lat.−32° 31′
.....	5 35.6	−67 39	.....	Gaseous nebula. Gal. long. 244° 32′, lat.−31′ 50′
.....	5 36.2	−69 45	.....	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright
.....	5 36.8	−69 44	.....	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright

[1] *Harvard College Observatory Circular* No. 60.

TABLE I.—*Continued.*

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m	° ′		
.....	5 37.6	−69 30	.....	Type V. Gal. long. 246° 41′, lat.−31° 32′
.....	5 37.7	−69 16	.....	Type V. Gal. long. 246° 25′, lat.−31° 32′
.....	5 40.7	−69 27	.....	Type V. Gal. long. 246° 37′, lat.−31° 16′
.....	5 40.9	−69 27	.....	Type V. Gal. long. 246° 37′, lat.−31° 14′
.....	5 41.4	−69 43	.....	Gaseous nebula. Gal. long. 246° 55′, lat.−31° 11′ Lines λ 5007, *Hβ*, *Hγ*, *Hδ* and *He*, bright
A. G. C. 8991	7 3.2	−23 41	6.3	Type I. *Hβ* bright
Z. C. 10h 1363	10 19.4	−59 8	8.8	Type I. *Hβ* bright
Z. C. 10h 2112	10 30.3	−47 53	9	Peculiar
C. P. D. − 58° 2845	10 49.7	−58 59	9.8	Type V. Gal. long. 256° 13′, lat.+0° 4′
C. P. D. − 61° 2577	11 39.6	−61 43	9.9	Type V. Gal. long. 262° 55′, lat.−0° 33′
Z. C. 11h 3668	11 54.8	−58 2	9	Peculiar
.....	13 26.4	−65 28	.....	Gaseous nebula. Gal. long. 274° 48′, lat.−3° 54′
−17° 3961	13 50.3	−17 45	8.0	Peculiar
−43° 9005	14 16.1	−43 41	10	Gaseous nebula. Gal. long. 287° 45′, lat.+15° 1′
Z. C. 14h 970	14 16.9	−47 4	9.5	Type IV.
.....	15 7.1	−59 28	.....	Type V. Gal. long. 287° 43′, lat.−2° 35′
C. P. D. − 65° 3171	15 46.7	−65 52	9.2	Peculiar
−40° 11127	16 58.1	−40 44	9.9	Gaseous nebula. Gal. long. 313° 11′, lat.−1° 4′
.....	17 3.5	−55 16	.....	Gaseous nebula. Gal. long. 301° 55′, lat.−10° 22′
−49° 11366	17 14.6	−49 22	10	Peculiar. Gal. long. 307° 49′, lat.−8° 27′
Z. C. 17h 1520	17 24.4	−51 0	8	Peculiar.
−33° 12168	17 26.5	−33 33	9.8	Type V Gal. long. 322° 18′, lat.−1° 35′
.....	17 33.5	−57 52	.....	Peculiar.
.....	17 38.1	−44 52	.....	Gaseous nebula. Gal. long. 313° 51′, lat.−9° 27′
A. G. C. 24406	17 52.7	−36 0	7.2	Type V. Gal. long. 320° 0′, lat.−7° 27′
.....	17 52.8	−56 16	.....	Type I. *Hβ* bright
−43° 12354	18 5.9	−43 43	10	Peculiar.
.....	18 11.1	−46 2	.....	Gaseous neubla. Gal. long. 315° 31′, lat.−15° 7′
−16° 4904	18 24.6	−16 59	9.8	Type IV
.....	18 27.9	−22 43	.....	Gaseous nebla. Gal. long. 338° 27′, lat.−7° 57′
−13° 5083	18 38.7	−13 20	9.1	Type IV
− 4° 4678	18 58.7	− 4 28	9.0	Type V. Gal. long. 358° 16′, lat.−6° 13′
− 9° 5069	19 11.0	− 9 14	10	Gaseous nebula. Gal. long. 355° 22′, lat.−11° 7′
−50° 12918	20 12.9	−50 8	10	Type IV

h m

0 56.0. Position for 1875, R. A. = 0h 55m 10s.3, Dec. = − 72° 50′ 18″. This fifth type star is in the Small Magellanic Cloud, and is the only object of its class so far found in this region.

1 6.2. Position for 1850, R. A. = 1h 4m 45s.2, Dec. = − 73° 59′ 43″. This nebula is in the Small Magellanic Cloud.

4 49.9. This, and the following twenty-seven objects are in the Large Magellanic Cloud. The number of stars of the fifth type, in this region, is thus increased from six to twenty-one.

4 57.3. A bright line appears near *Hβ* in the spectrum of this faint object. In such cases, the only way to decide whether the object is a gaseous nebula, a star of the first type having the hydrogen line *Hβ* bright, or a star of the fifth type, is to see if the wave-length of this line is greater than, equal to, or less

h m

than that of $H\beta$. This is done by superposing a chart plate of the region on a spectrum plate, so that the images of adjacent stars on the former coincide with the hydrogen line $H\beta$ in the images on the latter plate. Owing to the faintness of this object and the small dispersion, it is difficult to determine the exact position of the bright line.

4 57.5. See $4^h\ 57^m.3$.

5 40.7. This object was announced as a gaseous nebula in *N. G. C.* 2081, *Circular* No. 19. An examination, by the method described above (see $4^h\ 57^m.3$), however, shows that the spectrum is of the fifth type.

7 3.2. The bright hydrogen line in the spectrum of this star was found by Miss Cannon.

10 30.3. *Z. C.* 10^h 2112. A broad dark band in this spectrum, of somewhat shorter wave-length than $H\beta$, appears to coincide with the bright band characteristic of spectra of the fifth type. In fact, the spectrum of this star resembles that of a star of the fifth type reversed upon a continuous spectrum.

11 54.8. The spectrum of this star resembles that of *Z. C.* 10^h 2112.

13 26.4. Position for 1875, R. A. $= 13^h\ 24^m\ 41^s.8$, Dec. $= -65°\ 19'\ 50''$.

15 7.1. Position for 1875, R. A. $= 15^h\ 5^m\ 3^s.2$, Dec. $= -59°\ 22'\ 27''$.

15 46.7. Spectrum continuous. $H\beta$, $H\gamma$, and $H\delta$, bright.

17 3.5. Position for 1875, R. A $= 17^h\ 1^m\ 26^s.0$, Dec. $= -55°\ 14'\ 20''$.

17 14.6. The spectrum of this star resembles that of *Z. C.* 10^h 2112.

17 33.5. Position for 1875, R. A. $= 17^h\ 31^m\ 15^s.6$, Dec. $= -57°\ 50'\ 57''$. The spectrum of this star resembles that of *Z. C.* 10^h 2112. It also resembles that of the adjacent star A. G. C. 23935, announced as a variable in *Circular* No. 24.

17 38.1. Position for 1875, R. A. $= 17^h\ 36^m\ 18^s.8$, Dec. $= -44°\ 51'\ 4''$.

17 52.8. Position for 1875, R. A. $= 17^h\ 50^m\ 41^s.5$, Dec. $= -56°\ 16'\ 23''$.

18 5.9. The spectrum of this star resembles that of *Z. C.* 10^h 2112.

18 11.1. Position for 1875, R. A. $= 18^h\ 9^m\ 12^s.9$, Dec. $= -46°\ 2'\ 29''$.

18 27.9. Position for 1855, R. A. $= 18^h\ 25^m\ 9^s.1$, Dec. $= -22°\ 44'\ 44''$.

The bright line $H\beta$ in the spectra of η *Centauri*, *A. G. C.* 17739, and κ *Apodis*, *A. G. C.* 20878, has been found to be variable, by Miss A. J. Cannon. The star *Z. C.* 18^h 1935, announced as of the fourth type in *Circular* No. 32, appears to have a spectrum of the same class as *Z. C.* 10^h 2112, described above.

EDWARD C. PICKERING.

July 6, 1901.

LATITUDE AND LONGITUDE OF THE YERKES OBSERVATORY.[1]

THE latitude and longitude of the Yerkes Observatory were first determined by Mr. W. H. Wright in 1897, and the approximate values

[1] *Yerkes Observatory Bulletin* No. 18.

obtained were published in *Bulletin* No. 2. In the autumn of 1900, through the courtesy of the Superintendent of the United States Coast and Geodetic survey, Assistants C. H. Sinclair (chief of party) and O. B. French were detailed to determine the latitude of the Observatory and the difference in longitude between our transit room and the Coast Survey Station at St. Louis.

A full description of Zenith Telescope No. 4, and of the methods of observation and reduction employed in the determination of the latitude by Mr. French, may be found in *Report of the United States Coast and Geodetic Survey*, 1897–8, Appendix No. 7 (fourth edition), pp. 342, 347–350, 354–363, etc. The determination of the micrometer value by observations of λ *Ursae Majoris* on October 26 gave for the value of one turn 44″.60. The value as afterward computed from the latitude observations themselves by the method indicated on page 370 of the Appendix was 44″.6164. The column headed *Mm.* in the table shows the correction to the results from separate pairs, due to the change from the value 44″.60 to the value 44″.6164. The results for each pair of stars employed are given in the following table:

LATITUDE OF THE YERKES OBSERVATORY.

No. of pair	Catalogue Nos., *Gr. 10 Yr.* 1880	φ	Δφ	*Mm.*	φ Corrected for micrometer	*v*	*n*	*w*	*w*φ	Δφ
		° ′ ″	″	″	° ′ ″					
1	3534−3548	42 34 12.47	+0.17	+0.17	42 34 12.64	−0.01	6	29	18.56	0.00
2	3578−3587	13.13	− .49	− .13	13.00	− .37	6	19	19.00	− .36
3	3595−3610	13.22	− .58	− .08	13.14	− .51	6	29	33.06	− .50
4	3617−3631	12.73	− .09	− .14	12.59	+ .04	5	22	12.98	+ .05
5	3651−3662	12.07	+ .57	− .18	11.89	+ .74	5	20	−2.20	+ .75
6	3671−3677	13.00	− .36	− .15	12.85	− .22	5	28	23.80	− .21
7	3684−3724	12.30	+ .34	+ .06	12.36	+ .27	6	29	10.44	+ .28
8	3758−3760	13.15	− .51	+ .03	13.18	− .55	5	19	22.42	− .54
9a	3740−3783	12.46	+ .18	− .12	12.34	+ .29	1	12	4.08	+ .30
9	3758−3787	12.55	+ .09	+ .10	12.65	− .02	5	19	12.35	− .01
10	3806−3815	12.36	+ .28	+ .05	12.41	+ .22	5	14	5.74	+ .23
11	3820−3827	12.77	− .13	− .21	12.56	+ .07	6	14	7.84	+ .08
12	3806−3827	12.26	+ .38	− .04	12.22	+ .41	5	14	3.08	+ .42
13	3815−3820	13.02	− .38	− .13	12.89	− .26	5	14	12.46	− .25
14	3879−3891	12.63	+ .01	− .04	12.59	+ .04	6	29	17.11	+ .05
15	3915−3925	12 36	+ .28	+ .14	12.50	+ .13	6	29	14.50	+ .14
16	3939−3974	12.63	+ .01	+ .03	12.66	− .03	6	16	10.56	− .02
17	3995−4003	12.51	+ .13	− .04	12.47	+ .16	6	4	1.88	+ .17
18	4003−4018	12.76	− .12	− .07	12.69	− .06	6	19	13.11	− .05
19	4030−4044	12.65	− .01	− .09	12.56	+ .07	6	29	16.24	+ .08
20	19−52	12.82	− .18	+ .07	12.89	− .26	6	19	16.91	− .25
21	37−52	12.13	+ .51	+ .21	12.34	+ .29	5	19	6.46	+ .30
22	72−86	12.73	− .09	+ .01	12.74	− .11	5	28	20.72	− .10
23	114−127	12.57	+ .07	+ .09	12.66	− .03	5	22	14.52	− .02
24	154−157	12.71	− .07	+ .09	12.80	− .17	4	26	20.80	− .16
p=25		42 34 12.64	+2.97 −3.01	m=0.0082	42 34 12.63	−2.60 +2.73	132	522	336.42	

Probable error of a single observation $= \epsilon = \sqrt{0.0518} = \pm 0''.228$.

$$\epsilon_p^2 = 0.037 \qquad \epsilon^2 = 0.011.$$

$$\epsilon^2_{\frac{ss}{2}} = 0.037 - 0.011 = 0.026.$$

$$\text{Latitude Yerkes Observatory} = 42^\circ\ 34'\ 12''.00 + \frac{336.42}{522}$$

$$= \mathbf{42^\circ\ 34'\ 12''.64 \pm 0''.038}.$$

In the determination of the longitude, Transit No. 18 was mounted on the transit pier of the Yerkes Observatory, at a point 264 feet 5 inches (=0s.235) east of the center of the 40-inch equatorial pier. At St. Louis, Transit No. 19 was mounted on the brick pier erected by Professor Woodward in the east end of the Observatory of Washington University. This station is 1.2 feet (=0s.001) west of the Coast Survey Station of 1881. The results of the observations are given in the following table:

DIFFERENCE OF LONGITUDE BETWEEN ST. LOUIS, MISSOURI, AND THE YERKES OBSERVATORY, WILLIAMS BAY, WISCONSIN.

Date 1900	Observers at		Mean of W. and E. Signals	Personal Equation	Difference of longitude		Transmission time
	St. Louis	Yerkes Obs.	m s	s	m s	s	s
Oct. 8	O. B. French	C. H. Sinclair	6 36.013	+0.205	6 36.218	+0.031	0.067
9			.013		.218	+ .031	.046
10			.078		.283	− .034	.040
12			.072		.277	− .028	.042
			6 36.044				
13	C. H. Sinclair	O. B. French	.473	−0.204	.269	− .020	.033
14			.414		.210	+ .039	.053
15			.445		.241	+ .008	.034
16			.482		.278	− .029	.045
			6 36.453		6 36.249	±0.009	0.044

St. Louis (1881)—Yerkes Observatory Transit (1900) =
$6^m\ 36^s.248 \pm 0^s.009$

Longitude St. Louis (1881), latest adjustment	$6^h\ 00^m\ 49^s.256$
Longitude Yerkes Observatory Transit	5 54 13.008
Longitude Yerkes Observatory 40-inch Equatorial	**5 54 13.243**

I take pleasure in expressing the thanks of the Yerkes Observatory to Superintendents Pritchett and Tittmann and to Assistants Sinclair and French, of the Coast and Geodetic Survey, for the important results of this admirably conducted campaign.

GEORGE E. HALE.

August 13, 1901.